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CONSEIL PERMANENT INTERNATIONAL
POUR L'EXPLORATION DE LA MER

JOURNAL DU CONSEIL

VOL. VII · NO. 2

PUBLIÉ PAR LE BUREAU DU CONSEIL

RÉDIGÉ PAR

E. S. RUSSELL

EN COMMISSION CHEZ
ANDR. FRED. HØST & FILS
COPENHAGUE

Août 1932

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IMPRIMERIE BIANCO LUNO A/S

Solar Radiation and its Transmission through Air and Water.

By

W. R. G. Atkins,

Marine Biological Laboratory, Plymouth.

Energy distribution in sunlight.

The measurement of daylight is extraordinarily difficult because of its variability in quality, intensity and angular distribution. Results showing the relative energy at various wave-lengths have been given for pure sunlight by ABBOT, FOWLE and ALDRICH (1911, 1922) for cloudless, but not necessarily hazeless, days at Washington, Mt. Wilson and Mt. Whitney. These results have been extrapolated to determine

Table 1.
Solar Energy-Spectrum. Abbot.

Wave length	Mean intensity	Transmission	
		Washington	Mt. Whitney
μ	Arbitrary units	Fraction of 2	Fraction of 2
0.39	3614	0.445	0.800
0.43	5321	0.600	0.844
0.45	6027	0.640	0.875
0.47	6240	0.671	0.902
0.50	6062	0.705	0.919
0.55	5623	0.739	0.930
0.60	5042	0.760	0.940
0.70	3644	0.839	0.964
0.80	2665	0.865	0.976
1.00	1657	0.901	0.975
1.60	532[1])	0.930	0.963
2.50	43	0.870	0.945

[1]) Approx. same as at 0.30.

the curve outside the atmosphere and the fraction transmitted and received normally, is given, for the sun vertically overhead at each station. Table 1 shows the results for Washington and Mt. Whitney and in Fig. 1 the ordinates denote arbitrary energy units, k_λ and the abscissae wave-lengths, up to only 2.0 μ for convenience of scale. The curves *A*, *B* and *C* refer, respectively, to outside the atmosphere, Mt. Whitney and Washington, for normal incidence of zenithal sunlight.

To compute the transmission for other than zero zenith distances, the coefficients here given must be raised to a power equal to the secant of the zenith distance. This does not hold closely for zenith distances above 75°. In Fig. 2 the ordinates are transmission factors and the

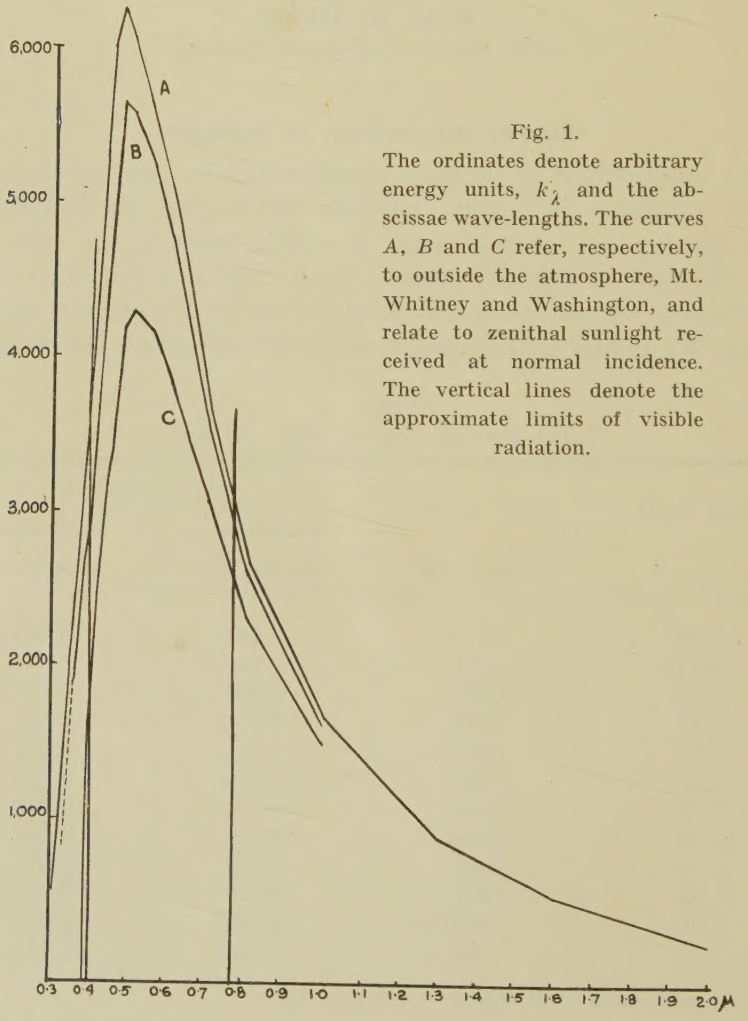

Fig. 1.
The ordinates denote arbitrary energy units, k_λ and the abscissae wave-lengths. The curves *A*, *B* and *C* refer, respectively, to outside the atmosphere, Mt. Whitney and Washington, and relate to zenithal sunlight received at normal incidence. The vertical lines denote the approximate limits of visible radiation.

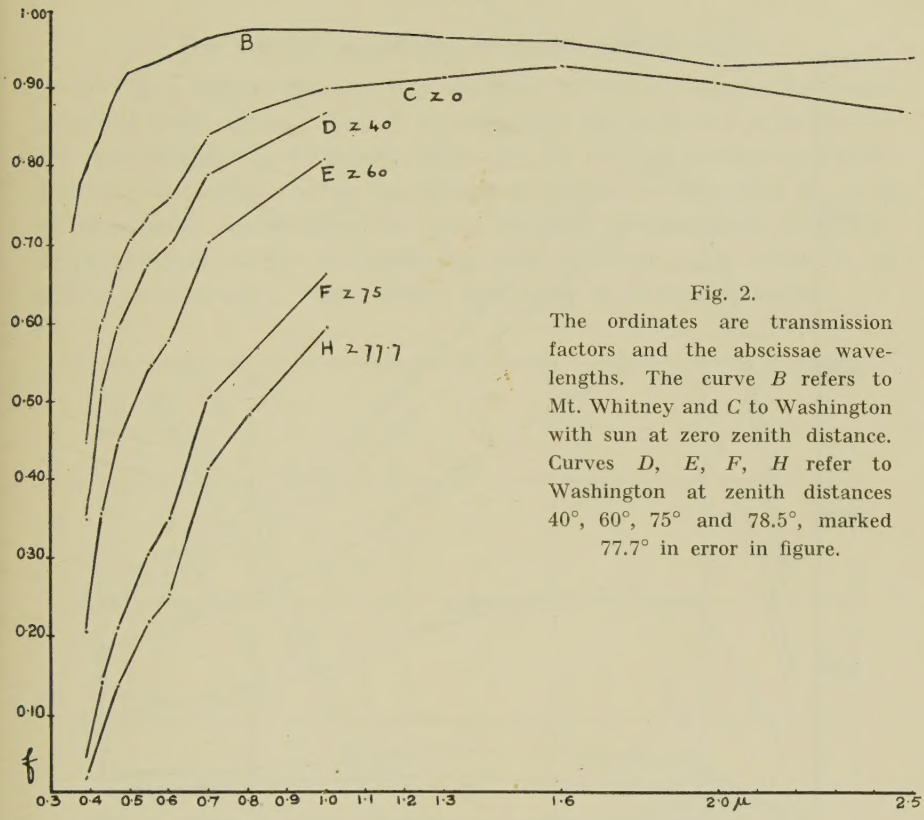

Fig. 2.
The ordinates are transmission factors and the abscissae wave-lengths. The curve *B* refers to Mt. Whitney and *C* to Washington with sun at zero zenith distance. Curves *D*, *E*, *F*, *H* refer to Washington at zenith distances 40°, 60°, 75° and 78.5°, marked 77.7° in error in figure.

abscissae wave-lengths. The curve *B* refers to Mt. Whitney and *C* to Washington at zero zenith distance. Curves *D*, *E*, *F*, *H* refer to Washington at zenith distances 40°, 60°, 75° and 78.5°. It is clear that with a declining sun the greater distance the rays have to traverse in passing through the atmosphere to reach the earth results in the almost complete cutting off of the shortest wave-lengths; this effect is often greatly enhanced by the presence of mist or dust, so that a low sun may appear a fiery red.

In Fig. 3 the arbitrary energy units are taken as ordinates but the abscissae are only carried on up to 1.0 μ. In it k_λ is multiplied by $f^{\sec z}$ to allow for the additional atmospheric distance traversed for different values of z, the zenith distance; the expression is then multiplied by cos z to correct from normal incidence to incidence upon a horizontal surface, such as upon the earth or sea. The curves then are for $k_\lambda f^{\sec z} \cos z$ and relate to Washington at zenith distances 0, 20, 40, 60, 75 and 78.5 for curves, *C*, *d*, *D*, *E*, *F* and *H* respectively. For Plymouth, England, latitude 50°, $z = 40$ at noon on April 16 and

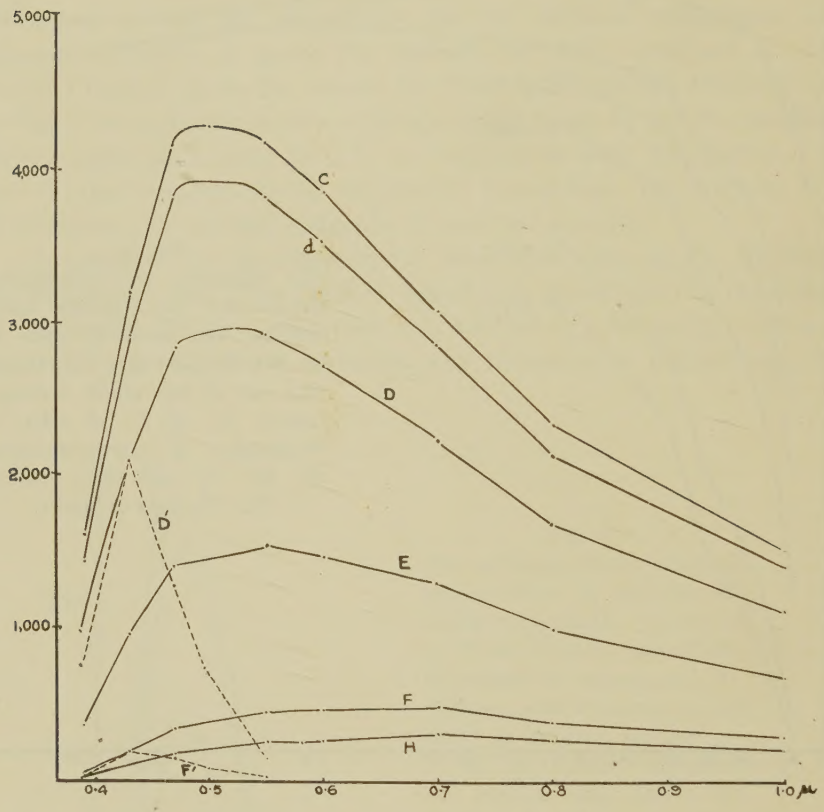

Fig. 3. The ordinates denote arbitrary energy units, against which is plotted $k_\lambda f^{\sec z} \cos z$; the abscissae are wavelengths. The curves relate to Washington at zenith distances 0, 20, 40, 60, 75 and 78.5 for curves *C*, *d*, *D*, *E*, *F* and *H* respectively. The dotted curves *D'* and *F'* were derived from *D* and *F* by multiplying the ordinates by the wave-length-sensitivity factors for a vacuum potassium photo-electric cell.

August 21; $z = 60$ at noon on February 23 and October 18th and $z = 75$ approximately at noon on December 22; at 10 a. m. and 2 p. m. on December 17—27 inclusive $z = 78.5$.

It may be seen that in curves *A*, *B* and *C*, Fig. 1 the maximum lies at 0.47, 0.47 and 0.50 μ respectively and in Fig. 3 the *C* maximum portion becomes flattened out and shifted towards longer wave-lengths, so that in curve *E* the maximum has shifted to 0.55 μ, well into the green, and lies at about 0.7 μ with $z = 75$. There is, therefore, in the course of the year, a shift of the maximum of the noon intensity — wave-length curve towards the red.

The colour sensitivity of photo-electric cells.

In Fig. 3 appear also two dotted curves D' and F'. These have been obtained from curves D and F by weighting the ordinates according to the wave-length — sensitivity data for the vacuum potassium photo-electric cell, so that when the energy of sunlight is measured by such an instrument one is taking the areas enclosed by the curves D' and F' as proportional to the corresponding areas of D and F, or rather up to 0.76 μ in each case, where visible light only is being considered.

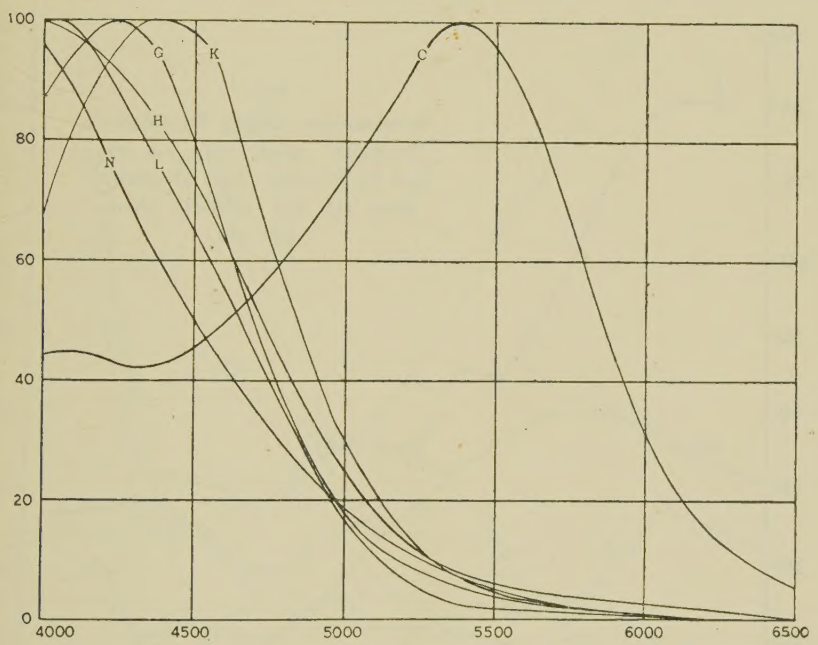

Fig. 4. The ordinates show the percentage sensitivity of the photometers for various wave-lengths plotted in Ångström units on the abscissae. The photometers contain photo-electric cells as follows:— *C*, a gas-filled caesium cell; *K*, a gas-filled potassium-hydride cell; *G*, *H* and *L*, vacuum potassium cells; *N*, a vacuum sodium cell.

Fig. 4 shows the percentage sensitivity of various types of photo-electric cells, (Poole and Atkins, 1928), as follows:— *N*, a vacuum sodium cell, whose maximum really lies off the diagram and for the pure metal is normally at about 3600 Å; *L*, *H* and *G* vacuum potassium cells; *K* a gas-filled potassium cell; *C* a gas-filled caesium cell. The last named has a curve more nearly like that of the human eye than any of the others. It is, however, for many reasons an unsatisfactory type of cell. It should also be remembered that the human eye is an entirely

arbitrary standard, which, though probably close to that of the fish according to Hess (1914), is yet quite unlike that defining the spectral efficiency of the photosynthetic process.

Photo-electric cells are now available, which are most sensitive not to blue, but to red. In order, therefore, to obtain a cell combination with a wave-length — sensitivity curve approximately horizontal to the wave-length axis one might, therefore, try combining such a filter as is used to reduce to daylight tint the preponderatingly red light of the gas-filled electric light bulb. Fig. 5 shows the transmission of Chance's "Daylight"

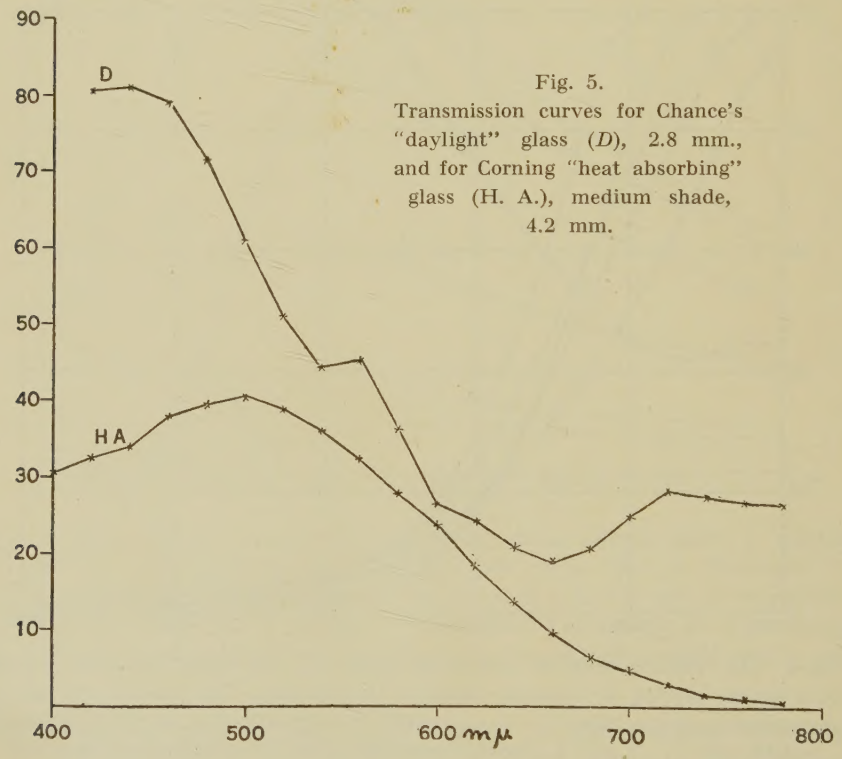

Fig. 5.
Transmission curves for Chance's "daylight" glass (*D*), 2.8 mm., and for Corning "heat absorbing" glass (H. A.), medium shade, 4.2 mm.

glass, 2.8 mm thick and of Corning "heat-absorbing" glass, medium shade, 4.2 mm (Atkins and Poole, 1931). In Fig. 6 is given the percentage sensitivity of a Burt vacuum sodium cell, *B*, and of a General Electric Company thin film vacuum caesium cell, type C. M. V. 6. Below are shown the sensitivity curves of such a cell under "Daylight" glass, *D* and heat absorbing glass, H. A. In the former both ends are high, the centre portion tolerably level. In the latter a fair degree of uniformity has been obtained between 440 and 640 m μ. This combination is useful in under-water photometry since the extreme red, being so rapidly

absorbed, is there of relatively little importance. As a measure of total radiation the former is probably preferable since the hump at the red end tends to compensate for the fact that the cell is insensitive to much of the infra-red and similarly at the blue end. The heat absorbing filter is, however, more useful in problems of photosynthesis when one wishes to consider the effect of red light, known to be important, without including the ineffective infra-red.

Fig. 6. Sensitivity curves of Burt sodium (*B*), G. E. C. thin-film potassium (K. M. 2) and G. E. C. thin-film caesium (C. M. V. 6) photo-electric cells mounted under opal glass. The curves marked *D* and *H. A* give the sensitivity of C. M. V. 6 (with opal) mounted under "daylight" and "heat-absorbing" glasses, respectively.

For measurements in the ultra-violet recourse may be had to a sodium cell, or even a potassium cell, combined with a filter of the "Wood's glass" type or one of the newer phosphatic red purple glasses. All such glasses transmit deep red also, but the sodium and potassium cells are quite insensitive in this region. A sodium cell with such a filter has a

maximum sensitivity at about 360 m μ. The anti-rachitic portion of the solar spectrum is usually taken as below 313 m μ where the radiation is normally of low intensity and is falling off very rapidly.

Diffuse Daylight.

As sunlight passes through the atmosphere a considerable amount of scattering and reflection takes place. The scattering by small particles affects the radiation inversely as the fourth power of the wave-length. So the scattered light, some of which reaches the earth, is relatively richer in blue, violet and ultra-violet as compared with direct sunlight. This is perhaps a long-winded way of saying that the sky looks blue when unclouded. Furthermore, in the upper atmosphere there is absorption of ultra-violet by oxygen, resulting in the formation of ozone, a subject which has received much attention of late from Dobson (1926) and his co-workers. Again, the infra-red is heavily absorbed by water vapour. It is most instructive in this connection to make visual observations through colour filters, especially on slightly hazy or foggy days, and such observations may profitably be extended to a flower garden. Spectroscopic observations of light from the sky, from clouds and in various situations should also be made. For this purpose it is convenient to observe a matt opal surface. Thus in a wood where a carpet of *Hedera helix* covered the ground, the light reflected from the Hedera was very faint, with a maximum in the green at 552 mμ. Light from an opal plate, lying horizontally on the Hedera, showed the red well, with an absorption band in the orange red; the green was bright, the blue less by far and cut off fairly sharply at about the *G* line, 431 mμ, though this appearance may be in part due to the lesser sensitivity of the eye in this region, since the daylight factor or percentage of the vertical component of the diffuse daylight from the whole sky, was only 0.9, as determined for blue light.

Much of the diffuse light is also polarized, the quarter of the sky in which polarization is a maximum depending upon the position of the sun and atmospheric conditions. Sometimes it is possible by looking through a Nicol prism and rotating it, to locate an object in the sky which has been followed with the naked eye till out of sight. In general by rotating the prism it is possible, in directions at right angles to the sun's rays, to increase the contrast between the polarized blue sky light and the less strongly polarized light from clouds. A proportion of the light reflected from the surface of the sea is also polarized. Thus by suitable adjustment of the prism the glitter of sunlight on water can be largely eliminated, and the peculiar streaks one sometimes sees running for long

distances at sea can be made absolutely to disappear. It is not possible, however, to increase the depth to which the Secchi disc can be seen by the use of the prism or of any kind of light filter. Objects floating on or near the surface may, however, be located more readily with the help of a Nicol prism to eliminate glitter, and colour filters may also be of use, especially those which increase the contrast between the colour of the water and of rusty objects or wooden spars. For such purposes a "minus green" filter may serve, as it enhances yellow tints by contrast; a didymium glass, which leaves colours in general without much alteration but appears to intensify red, is at times of utility. The value of a deep red filter in eliminating the scattered blue light of haze is most striking; where the light is poor a yellow filter may be substituted.

Precise figures have been given for the spectral energy distribution of sunlight; to do so for skylight would scarcely be profitable, as it varies so much from hour to hour and from one part of the sky to another. It is possible, however, to take the proportions of red, green and blue under certain conditions as a standard and to measure other lighting conditions by reference to this standard.

Colour factors of various types of illumination.

Colour filters may be used to isolate different portions of the spectrum. These should be chosen with great care and if possible examined to ascertain that they transmit their proper colours without contamination by more or less small amounts of others. In particular blue filters are liable to transmit in the far red, and green may transmit quite freely in that region also. To the eye two green filters may appear almost identical, yet their behaviour towards a red sensitive photo-electric cell may be quite different; the explanation lies in the high sensitivity of the eye to green and its low sensitivity to deep red, whereas the sensitivity of the cell is just the opposite. One can, however, make simple visual tests to eliminate faulty filters by taking a red filter and viewing an electric light bulb, which is rich in red light. On interposing a pure blue filter the light becomes invisible, whereas an impure blue may show a surprising amount of red. Similarly with a green filter, if pure, the field appears black; if impure a deep red is seen. No reliance should thus be placed on the spectrophotometric absorption curves, photographically obtained, and supplied by makers of filters in cases where they end at 700 mμ. Furthermore filters may differ quite considerably, as is admitted, within the same reference number.

In working with colour filters it is necessary to bear in mind that their absorption depends upon the angle of incidence of the light, so that

a surface-flashed opalized glass should be used to diffuse the light before it reaches the filter; the completely diffused light then traverses a path through the latter which is independent of the original angle of incidence. There are other reasons connected with the construction of a photo-electric cell which also render it imperative that a diffusing surface should be used unless the light is always incident at the same angle.

Now if we decide to regard as "white", i. e. as standard, any given type of illumination, we can find ratios green/blue, yellow/blue and red/blue for this illumination and also for any other illumination whose colour we wish to specify. The ratio green/blue for the given illumination to green/blue for the standard may be called the "Colour Factor" of the given illumination for the green filter, and so on, the filters being defined by their spectral transmission curves. The blue screen has been taken as a standard, since all our previous work has been done with blue-sensitive cells, whose sensitivity curves approximated to that of the C. M. V. 6 cell combined with the blue filter.

Table 2.
Colour factors, photo-electrically determined.
The grey-sky light on September 19 is here taken as standard.

Date	G.M.T.	Place and Conditions	Colour Factors (Blue = Unity)		
			Green	Yellow	Red
1929					
Sept. 18	10.40-11.45	Laboratory roof, Plymouth, sun (α = 40°) and blue sky.....	1.00	1.00	0.95
Sept. 19	1.50-2.15	Antony, on lawn, sun obscured	1.00	1.00	1.00
Sept. 24	3.45-4.0	Antony, on lawn, sun behind trees, blue sky, clouds.....	0.88	0.59	0.49
Sept. 25	2.50-3.15	Do.	1.00	0.68	0.55
1930					
May 26	12.20-12.30	Roof of Royal Dublin Society Laboratory, sun (α = 58°), blue sky.....	..	1.43	1.11
		Do., blue sky alone.....	..	0.56	0.41
		Do., sunlight alone, by differences	..	2.04	1.64
		Carbon arc lamp	1.52	3.28	2.90
		Motor head-lamp, gasfilled,			
		10.0 volts.....	1.64	6.85	6.45
		11.0 —	1.75	6.65	6.28
		12.0 —	1.87	6.49	6.07

As an example, the ratios for the blue-sky light on September 24th, about 4 p. m., were green/blue, 0.097; yellow/blue, 0.913; red/blue, 0.790; while for mixed sunlight and sky light, with clouds, in the forenoon of September 18th the ratios were, green/blue, 0.111; yellow/blue, 1.55; and red/blue, 1.535. If we take the blue-sky light as a standard, we get the following figures for the colour factors of the mixed light:— green, 0.111/0.097 = 1.15, yellow 1.55/0.913 = 1.70; and red, 1.535/0.079 = 1.94. It will be seen that, for the light chosen as a standard, the colour factor with every screen is, by definition, unity, and the magnitude of the factor for any other illumination is a direct measure of the relative intensity of the corresponding colour, blue being always taken as unity.

In Table 2 are shown the colour factors of various types of illumination. (Atkins and Poole, 1931).

Having now given a brief account of the composition of light as it reaches the earth, some attention will be paid to its intensity.

The intensity of solar radiation.

As a mean of 696 determinations at Washington the value 1.932 gram calories per square centimetre per minute was obtained for normal incidence outside the atmosphere; this is termed the solar constant of radiation. Between the limits 0.3 and 3.0 μ it may be thus divided:— 0.3—0.4 μ, 0.232; 0.4—0.76 μ, 0.715; 0.76—3.0 μ, 0.985 g. cal./cm^2 min. The division is approximately ultra-violet, 12 %, visible 37 % and infra-red 51 %. As previously mentioned the absorption by oxygen in the upper air causes a very abrupt falling off in energy towards the ultra-violet end. According to the work of Fabry and Buisson (1921, 1922) under the best conditions in the South of France the relative intensities are as follows:—

λ in mμ	Relative intensities.
314	22,400
299	1,320
292	22
290	0.02

Measurements were made by Abbot, Fowle and Aldrich (1913) of the relative brightness of the sun and clear sky, at Flint Island, in the South Pacific Ocean, on December 29th, 1907. They obtained the brightness over the whole sky, the measurements refer to all radiation capable of passing 3 mm. thickness of glass, as follows:—

Ratio of total radiations, sky to sun, 9.45—10.40 a.m.

For equal angular areas.		For the whole sky.	
Normal Incidence.	Sky on Horizontal	Normal Incidence.	Sky on Horizontal.
6.36×10^{-6}	3.02×10^{-6}	0.57	0.27

At noon on the same day the intensity of solar radiation, received normally, was 1.326 g. cal./cm.^{2} min. by "Smithsonian Revised Pyrheliometry". According to the figures quoted, the sky at sea-level on this occasion furnished to a horizontal surface 27 % as much radiation as the direct sun to a surface of equal area at right angles to the sun beam. According to this the sun's radiation, normally received, is 3.71 times that from the whole sky as received on a horizontal surface.

The ratio of total to diffuse vertical illumination.

A number of direct determinations have been made by Atkins and Poole (1931, 1932) of the ratio, β, of total to diffuse vertical radiation in different regions of the spectrum. Some of these are shown in Table 3, in which the ratio of sunlight to sky light, $\beta - 1$, progressively decreases from 4.5 for infra-red at noon to 1.1 for the ultra violet around 360 mμ;

Table 3.

Determinations of ratio of total to diffuse light.

On laboratory roof parapet, at Plymouth, August 17th, 1931, with type C. M. V. 6 photo-electric cell. Clear blue sky, a few white clouds.

G.M.T.	Transmitted by filters and opal glass	β
11.25	Spectrum to 360 mμ ultra-violet end	3.9
11.28	Infra-red and red to 710 mμ	5.0
11.34	Infra-red and red to 660 mμ	5.4
11.37	Infra-red and red to 610 mμ	5.1
11.40	Infra-red, red and yellow to 540 mμ	4.2
11.43	Red and yellow, 740—540 mμ	3.3
11.49	Green, 570—490 mμ	2.7
11.52	Pure blue and violet 480—340 mμ	2.5
11.55	Impure blue, infra-red and red to 700 mμ, then 490—370 mμ	2.8
12.0	Infra-red and red to 710 mμ	5.5
12.3	Do., cloud approaching sun	4.4
12.10	Do., very clear	5.9
12.13	Blue green, 590—390 mμ, no opal	4.2
12.16	Violet, 410—390 mμ, no opal	2.4
12.31	Ultra-violet, 410—300 mμ, no opal	2.1
12.40	Ultra-violet, around 360 mμ, no opal, Burt sodium cell	2.2

for the anti-rachitic portion, 313—300 mμ or slightly below, it would appear that the sky light is as intense on a horizontal surface as is the sunlight. With the sun at a greater altitude the sunlight values would naturally be increased, but these figures are fairly typical of clear summer weather.

Approximate energy measurements using a photo-electric cell.

Curves have been obtained in various places giving the daily normal solar radiation or the vertical component of the radiation from the whole sky, as described by Corless (1911) for South Kensington, London, using the Callendar electrical recorder. These values are more nearly comparable with the photo-electric records obtained at Plymouth (Atkins and Poole, 1930), than are any of the others, since the climate is not very dissimilar and Plymouth is only one degree of latitude further south. The comparison of the records has not as yet been properly carried out, but from records obtained by the two methods for September 1st, which, though the years were not the same, was in each year a calm cloudless day, it may be taken provisionally that the energy received from an illumination of 1,000 metre-candle hours is roughly 0.75 g. cal./cm.^{2}. In this the illumination was measured by a sodium photo-electric cell, standardized against a similar potassium cell, calibrated by means of a carbon arc.

The penetration of solar radiation into and through water.

The subject has been dealt with by the writer in a previous (1926) communication to this journal. The present account is intended to be a continuation of the earlier one, with such general introduction as may appear necessary.

If we consider homogeneous radiation incident normally on a plane water-surface and denote the intensity immediately below the surface (the sub-surface intensity) by I_o, and that at a depth x by I, then:— $I = I_o e^{-\mu x}$ where e represents the base of the natural logarithms, $e = 2.71828$, and μ is a value defined by the above equation and termed the coefficient of absorption, or, less ambiguously, the transmissive exponent (Gibson 1925).

The reason for using the latter term is that the constant in two other expressions have also, by various authors, been termed the coefficient of absorption.

When the angle of incidence is not normal, the path of the refracted ray through the water will be greater than the depth, the expression then becomes $I = I_o e^{-\mu l}$, where l is the length of the path. In open water,

however, the illumination is received at all angles; moreover, as a rule the state of the surface causes rapid alterations in the angle of incidence. Furthermore, reasons have been adduced for thinking that even in the clear water of the English Channel, 20 miles from land, the light may be considered as having, at least at depths below 10 m., an average altitude of between 50° and 60° (1928). The light from a supposedly uniformly illuminated hemisphere of sky may be represented as having an altitude of 30°. Taking the index of refraction for sea water as 1.338, this would give, for the refracted beam, an altitude of 50°. It would probably be more nearly correct, on an average, to take the altitude of the refracted beam as 55° or even perhaps 60°, and to calculate the transmissive exponent from a depth $x \sin \alpha$, or x cosec r, where α and r are respectively the angles of altitude and refraction. In view of the uncertainty attaching to the resultant angle of the refracted beam Poole and Atkins have calculated the "vertical transmissive exponent", from the depth, x, which will give consistent results.

This was tested as follows, using a photo-electric method which is described further on; measurements were made in the open sea at 9.22, 10.28 and 12.6, G. M. T., over the range 0—40 m., and gave $\mu_v = 0.121$, 0.121 and 0.124, respectively, while the sun's altitude varied from 24° to 31° and 35°; the sea was calm, with a moderate swell. (Data of Series 21, $^6/_{10}$ 1927).

Again, when the sun is hidden by a cloud the angular distribution of the light is obviously altered as well as the total vertical intensity, yet since μ_v remains unchanged it follows that the mean path through the water must have remained the same. For example, consecutive measurements were made, over the range 5—15 m., when the sunlight was reduced in intensity by a light cloud, when it was nearly clear and quite clear, the values of β being 2, 3.5 and 4 respectively, for the blue light affecting a vacuum potassium cell; the corresponding values of the vertical illumination in air were 49, 81 and 121 thousand metre candles; the values of μ_v were identical, 0.077, in each case (Data of Series 28, $^{19}/_4$'28). The sun's altitude was 51°; the determinations were made between 12.20 and 12.40, under a clear sky with white clouds. There was at the time a light north-westerly wind with a slight swell.

The value of μ_v will naturally be different in different parts of the spectrum. As usually given it is that for the light to which a potassium cell, vacuum or gas-filled, responds; the region of maximum sensitivity is around 440 mμ as may be seen in Fig. 4. The coefficient is that for the water together with the plankton organisms and inorganic matter in suspension; its variation is, therefore, an indication of the quantity of suspended matter.

An idea of the submarine illumination with different values of μ_v may be obtained as follows:— In Cawsand Bay, on a rough day when the bottom deposits were stirred up $\mu_v = 0.81$, whereas on a calm day the value $\mu_v = 0.165$ was obtained. Since $I = I_0 e^{-\mu x}$, where $x = 10$ metres, the percentage of the sub-surface illumination is $I = 100 \times \frac{1}{2.718^{0.165 \times 10}}$ for the clear day and $I = 100 \times \frac{1}{2.718^{0.81 \times 10}}$ for the turbid day; these give respectively 19.2 % and 0.033 %. Alternatively we may say that the turbid water reduces the illumination to $\frac{1}{e}$, viz. to 0.368 in 1.23 metres, and so on for each of the 8.1 times that 1.23 is contained in 10. But the clearer water reduces the illumination to 0.368 in 6.06 metres, and this process is only repeated 1.65 times in the 10 metres. In working out results one can read off values of e^{-x} from a table, if x be known, or it can be determined from the percentage illuminations at any two depths; denoting these by p_1 and p_2 and the difference in depth by δ, and transforming from natural logarithms to the base ten, then

$$\mu = \frac{2 \cdot 3}{\delta} (\log_{10} p_1 - \log_{10} p_2).$$

If now calculations be made at a series of depths, taking $\mu = 0.10$, it is possible to write down the percentages transmitted for greater or lesser values of μ, merely by inspection for even multiples or sub-multiples of μ, for with $\mu = 0.20$, the value $\frac{1}{e}$ is reached at 5 m., instead of at 10 m., and with $\mu = 0.05$ it is reached at 20 m., and similarly for other values and depths. Table 4 shows the percentages of the sub-surface illumination transmitted to certain depths for various values of μ. The depths 244 and 435 m. were included since they were the depths reached in the bathysphere in dives Nos. 7 and 10 (Beebe and Hollister, 1930).

In the last column $\mu_v = 0.08$ is an approximation to the value found for the clearest considerable water column in the English Channel, viz., 0.077. The table, therefore, covers a wide range of values for blue light; these vary from 0.8 found for turbid inshore waters to what seems a possible value, 0.025, for the clearest ocean water; that for pure water transmitting blue light being has been given by Sawyer (1931), as 0.015 between 460 and 490 mμ. If we take a high, though quite possible value, 100 thousand metre-candles (k. m. c.) for the sub-surface illumination, it may be seen that the light seen by Beebe at 435 m. could scarcely have been more than the blue portion of slightly under 2 metre-candles.

Table 4.
The percentage of the sub-surface light transmitted to various depths for different values of μ.

m	$\mu = 0.80$	0.40	0.20	0.10	0.05	0.025	0.08
1	45.0	67.0	81.9	90.5	..	..	..
2	..	45.0	67.0	81.9	90.5	..	..
3	..	..	54.9	74.1	..	..	..
4	..	..	45.0	67.0	81.9	90.5	..
5	..	13.5	36.8	60.7	..	..	..
6	..	..	..	54.9	..	..	..
7	..	..	..	49.7	..	..	..
8	..	..	..	45.0	67.0	81.9	..
9	..	..	..	40.7	..	..	..
10	0.033	1.83	13.5	36.8	60.7	77.9	45.0
15	..	0.248	4.98	22.3	..	..	..
20	..	0.033	1.83	13.5	36.8	60.7	..
25	..	0.004	0.674	8.20	..	..	..
30	..	..	0.248	4.98	22.3	..	..
40	..	..	0.033	1.83	13.5	36.8	..
50	..	..	0.004	0.674	8.20	..	..
60	..	..	..	0.248	4.98	..	..
70	..	..	..	0.091	..	..	..
80	..	..	..	0.033	1.83	13.5	..
90	..	..	..	0.012	..	..	..
100	..	..	..	0.004	0.674	8.20	0.0335
110	..	..	..	0.001	..	..	..
200	..	..	..	..	..	0.674	0.000,001
300	..	..	..	..	..	0.0553	..
400	..	..	..	..	..	0.0045	..
435	..	..	..	..	..	0.0018	..
244	..	..	..	..	..	0.224	..

As far as plant growth is concerned the very low illuminations are of no interest, being found far beyond the compensation point, namely, the depth at which photosynthesis and respiration balance on a twenty-four hours average.

Very feeble intensities have been detected by long exposures of photographic plates; these will be considered first of all.

Photographic researches into under-water illumination.

In the "Michael Sars" Expedition of 1910 Helland-Hansen (1931) found, by the use of panchromatic Wratten plates and colour filters, that even with a clear sky at noon on June 6, in the clear water of the

Sargasso Sea, there was but little red at 100 m., at 500 m., blue could be detected, but no green; it required 80 minutes exposure, without a colour filter, to affect the plate at 1,000 m., and even 2 hrs. at 1,700 m. had no effect; at 500 m. the light was not all completely diffuse, shadows were cast.

In the Mediterranean an elaborate research was carried out by GREIN (1913, 1914) along similar lines. His work appears to be the photographic method at its best. Tables 5 and 6 give GREIN's results and in Table 7 are shown the values of μ_v as calculated therefrom, since GREIN did not give the absorption coefficients. The tables bring out the differences in

Table 5.

Grein's results, showing the illumination at various depths in the Mediterranean, taking that at 1 m as 1,000.

m	Red	Orange-Yellow	Green	Blue-Green	Blue	Blue-Violet
5	3.7	2.5	250	250	450	866
10	2.7	2	166	166	437	800
20	0.03	1.2	5.8	21	277	666
50	0.0021	0.032	2.2	2.5	201	200
75	..	0.008	0.75	2.2	25.6	100
100	..	0.001	0.03	0.033	5.5	10
200	..	..	0.004	0.01	0.04	1
500	..	..	0.0016	0.004	0.004	0.1
1,000	..	..	..	0.0003	0.0001	0.003
1,500	..	..	..	..	..	(0.00001)

Table 6.

Grein's results, showing the proportion of each spectral region in the total light at each depth, taking the total as 1,000.

m	Red	Orange-Yellow	Green	Blue-Green	Blue	Blue-Violet
1	96.7	165.7	165.7	165.7	198.9	207.3
5	0.98	1.18	117.3	117.3	254	508.8
10	0.34	1.06	89.64	89.64	282.2	537.1
20	0.018	1.05	4.68	17.26	279.7	697.2
50	0.0025	0.069	4.53	5.04	486	504
75	..	0.054	4.73	14.2	193.6	787.5
100	..	0.0052	1.56	1.73	346.2	650.8
200	..	..	3.18	8.06	37.16	952
500	..	..	12.27	30.63	30.8	920.3
1,000	..	..	..	74.6	37.31	881.1
1,500	..	..	..	..	..	(1,000)

Table 7.
Values of the vertical absorption coefficient, μ_v, calculated from Grein's photographically determined illuminations. The value for 1—5 m. is entered opposite 5 m., and so on.

m	Red	Orange-Yellow	Green	Blue-Green	Blue	Blue-Violet
5	1.40	1.49	0.346	0.346	0.199	0.036
10	0.063	0.044	0.082	0.082	0.006	0.016
20	0.450	0.051	0.335	0.207	0.045	0.018
50	0.089	0.121	0.032	0.071	0.011	0.040
75	..	0.055	0.043	0.005	0.082	0.028
100	..	0.083	0.129	0.168	0.061	0.092
200	..	..	0.021	0.012	0.049	0.023
500	..	..	0.003	0.003	0.008	0.008
1,000	..	..	..	0.005	0.007	0.007
1,500	..	..	..	..	..	0.011

the penetration of the various parts of the spectrum and show clearly that at great depths blue and violet, or the latter alone, remain. The irregularity of the absorption coefficient shows, however, that the measurements can have a qualitative value only, since one cannot imagine the water to be so highly heterogeneous, not only as regards one depth range and the next, but with respect to one colour and another at two pairs of depths, an increase in transmission in one corresponding to a decrease in another.

Further photographic determinations, down to at most 25 m., usually less, were carried out in fresh waters by Gruber (1924) and Oberdorfer (1929) using the neutral tint wedge photometer. Klugh's (1925) apparatus has been mentioned in the earlier review, as have also the spectrophotometric measurements of Knudsen (1922). The latter worked down to 9 m. in Nyborg Fjord and found the absorption coefficient had a minimum in the green around 510 mμ.

Measurement of total under-water radiation in lakes.

Much work upon the penetration of radiation through fresh-water lakes has been carried out by Birge and Juday, (1921). Using Mendenhall's pyrlimnometer they studied the waters of Lake Seneca. The pyrlimnometer consists of a receiver containing 20 small thermocouples which can be lowered into the water to any desired depth and alternately exposed to the sun and covered. The current thus generated is measured by the deflections of a D'Arsonval galvanometer on shore, which is connected with the receiver by an insulated cable 100 m. long. The results

for Lake Seneca are shown in Table 8. The great difference between pure water and lake water is probably due chiefly to suspended matter, as there was very little tint in the water due to substances in solution. The suspended matter was in the main fine silt, though some was of organic origin.

Table 8.

Radiation in gram calories per square centimetre per minute. In Lake Seneca, August 1st, 1918. The last percentage column shows approximate values for pure water.

m	Cal./cm² min.	%	m	Cal./cm² min.	%	m.	%
In air	1.30	100	3.50	0.12	9.0	Air	100
0.25	0.41	31.8	4.00	0.10	7.7	1	47
0.50	0.38	29.0	5.00	0.07	5.4	5	29
1.00	0.28	21.4	6.00	0.05	3.8	10	23
1.50	0.23	17.4	7.00	0.035	2.7	..	..
2.00	0.20	15.0	8.00	0.023	1.8	..	..
2.50	0.17	12.8	9.00	0.017	1.3	..	..
3.00	0.14	10.9	10.00	0.013	1.0	..	..

In pure water transmission through the first two metres is much smaller than through the succeeding metres. This is due to the rapid absorption of the rays of the red end of the spectrum as compared with that of the shorter waves. The distinction is less clearly marked in lake waters in which the large non-selective absorption due to turbidity and the selective absorption due to the tinting of the water obscure the effect of the selective absorption of the water, as water, after the first metre has been passed. In that metre is absorbed practically all of the energy contained in the portion of the spectrum lying below the *A* line ($\lambda = 7594$ Å), which is commonly taken as the limit of the visible spectrum.

Birge and Juday state that the percentages given in Table 8 vary somewhat with the sun's altitude. Under the conditions prevailing at the time, the sun's rays passed through 10.0 m. in reaching a depth of 9.4 m. The direct sunlight is considered as supplying about two-thirds of the energy received by the lake, the remainder coming from the sky during sunshine and in cloudy periods.

These valuable researches have now (1929, 1930, 1931) been extended to a large number of American lakes.

The thermo-couples, originally made of iron and constantan were

later made of bismuth and silver, which give nearly twice as great an electromotive force. Instead of a D'Arsonval galvanometer on shore, a Rawson millivoltmeter has been used in a boat on the lake in calm weather. The measurements have been carried down to 10 m., by 1 m. steps, in cases where the sensitivity of the apparatus permitted such a depth being reached. In general an attempt was made to trace the radiation down to a level from which it would be easy to determine the depth at which only one per cent. of the energy of the incident radiation would be left. This aim was facilitated, especially in the lakes with deeply tinted waters, by the obtaining of a millivoltmeter of the semi-suspended type which was six times as sensitive as that used formerly.

Two types of glass cover were used for the thermopile — a flat piece of plate glass and a hemispherical dome. The dome, which was used more than the other type in the earlier work, has the advantage that its readings in air can be directly compared with those of the Callendar sunshine-recorder, and so furnish a base for computing results in cal./cm.^{2} min. It has the disadvantage of calling for a large correction for observations in water, due to the lens effect of the spherical water-glass surface. The flat cover needs careful correction for readings in air, since the percentage of radiation transmitted by the glass will vary with the zenith-distance of the sun, but the ratio between the readings in the air and in the water is more easily determined. The two instruments are said to be equally good at depths of one metre or over, where the infra-red radiation has been absorbed and where the object is to ascertain the transmission of the water between various depths. It is assumed in this that the angular distribution of the light in the water does not vary from 1 m. downwards. Corrections have been introduced for the reflection losses at the glass-air surface of the apparatus and for the zenith distance of the sun and the cosine of the corresponding angle of refraction. No correction has been applied for the value of the radiation from the sky as a general rule; such radiation is not likely to be less than 16 per cent. of the total. Schmidt (1908) has given the value 17.3 per cent. for the amount of sky radiation reflected from a smooth surface if equal amounts of radiation are assured to come from equal areas of sky. On this assumption the sky-radiation passes through 1 m. of water in reaching an average depth of 84 cm. Owing to the uncertainty as to the angular distribution and losses due to reflection and shading by the boat Birge and Juday concluded that it is practically impossible to do anything with sky-radiations under the conditions of observation in a small boat. It was also impossible for them to work in rough water but it was found that ripples caused but small reflection losses, about one per cent. This was

verified by direct experiment. The large losses found in the English Channel, using the photo-electric method, may in part be accounted for by the fact that really rough water at sea contains a considerable amount of air in the form of minute bubbles. Some of the results are shown in Table 9.

Table 9.

Transmission of solar radiation by Wisconsin lakes.

D, transparency in metres, as measured by a Secchi disc 20 cm. diameter. Colour, *C*, is measured by the U. S. A. platinum-cobalt scale; *O* indicates no brownish or yellowish tinge. *R* denotes radiation in cal. cm^{-2} $min.^{-1}$ received at the time of observation on a horizontal surface in air. Per cent. at 100 cm., denotes the percentage of the air radiation as corrected for the effect of the glass cover and for the cosine of the angle of refraction of the direct rays of the sun. Per cent. transmission, in these columns the observed values are corrected for cosine, radiation being assumed to be normal to surface of lake and to be all direct sunlight. One per cent. at metres, the figures show the approximate depth at which is found one per cent. of the radiation present at the surface. The absorption coefficient, μ, between 1 and 2 m., also 4—5 m., as now calculated from Birge and Juday's results.

Lake	Date	D	C	R	Per cent at 100 cm.	Transmission per cent				1 % at m.	μ	
						1-2 m.	2-3 m.	3-4 m.	4-5 m.		1-2 m.	4-5 m.
Adelaide .	$^{5}/_{8}$ 27	3.1	38	1.06	11 7	30	37	..	..	3 4	1.20	..
Big.....	$^{26}/_{7}$ 26	3.4	8	0.72	18.8	50	..	..	..	5.3	0.69	..
Blue.....	$^{30}/_{6}$ 26	4.9	8	1.05	28.5	64	64	67	66	8.7	0.45	0.41
Crystal ..	$^{22}/_{7}$ 26	8.8	0	1.05	35.3	78	80	80	84	17.4	0.25	0.17
Crystal ..	$^{17}/_{8}$ 26	9.5	0	0.76	35.4	75	81	78	80	18.7	0.29	0.22
Crystal ..	$^{19}/_{7}$ 27	10.7	0	1.08	35.8	72	77	79	83	18.8	0.33	0.19
Mary	$^{12}/_{7}$ 26	2.0	100	1.36	6.3	39	..	..	..	3.0	0.94	..
Spider ...	$^{5}/_{8}$ 27	2.0	8	1.21	11.3	40	40	40	..	3.6	0.92	..
Trout....	$^{29}/_{6}$ 26	5.3	6	1.28	26.5	63	67	69	71	10.0	0.46	0.34
Trout....	$^{26}/_{8}$ 26	5.3	6	0.88	23.0	61	65	65	69	7.9	0.49	0.37
Trout....	$^{23}/_{6}$ 27	3.7	6	1.08	23.5	61	60	..	..	7.2	0.49	..
Turtle ...	$^{5}/_{8}$ 27	1.7	91	1.22	4.2	18	..	..	..	1.9	1.71	..
Weber...	$^{13}/_{8}$ 27	8.0	0	0.81	38.5	72	74	77	78	15.0	0.33	0.25
Wild Cat.	$^{26}/_{6}$ 27	2.4	18	1.06	16.3	38	37	..	..	3.9	0.96	..

From these figures it may be seen that only in the clearest lakes does as much as one-third of the total radiation penetrate to 100 cm. and only in about half the lakes, including the clearest, does one-quarter of the radiation penetrate the surface and reach 100 cm. The values of μ are for the most part high, but for the clearest lakes they are quite

comparable with those of μ_v found for sea-water for blue light, taking the 4—5 m. range; over the 1—2 m. range the absorption is in every case greater, as a greater proportion of red light is present. Since the light energy absorbed is converted into heat it follows that the first metre of the water receives by far the greatest amount of the heat. Nevertheless in the clearer lakes a proportion of the total radiation does penetrate below the thermocline, and slowly warms the deeper water.

This effect is mentioned by Birge and Juday, and has also been considered by Helland-Hansen (1931) and by Atkins and Poole (1932).

Thermopile measurements of the penetration of light of different wave-lengths into lakes.

In the 1929 work a large surface Moll thermopile was used and with this and the more sensitive millivoltmeter radiation could be measured until it had been reduced to about 0.1 per cent. of its value in air. It was mounted so that by rotating a disc it could be exposed uncovered or covered by an opaque lid or by Wratten light filters blue, red or yellow — followed by the uncovered position again. The order was chosen so that with the radiometer in the water the galvanometer reading would increase from blue to the uncovered position. A green filter was also used separately. Some of the interesting results obtained are shown in Table 10. Readings could be taken very quickly in favourable, almost cloudless weather, which constituted about half of the working period. When the radiometer was lowered from the warmer water of the epilimnion into the colder water below the thermocline, it was necessary to wait about 5 minutes until it had attained the temperature of its new surroundings before making measurements, otherwise the radiation from the vessel to the thermopile or vice versa would have caused an error.

This selection of their interesting results needs but little comment. It will be seen that the lakes with deeply tinted water absorb blue light very rapidly and even the green and yellow in some cases, so that, as in Lakes Helen, Little Pickerel, Mary and Midge, the maximum transmission is in the red. More usually transmission is greatest in the yellow, as in eleven out of the eighteen lakes shown in Table 10, but including two in which yellow and green are transmitted equally. In the clearest lakes transmission was greatest in the green, as found by Knudsen in Nyborg Fjord, but never in the blue as in the open sea far out. In addition to the percentage transmission, as given by Birge and Juday, the values of the coefficient of absorption, the transmissive exponent, have also been calculated. These authors also use a "coefficient of

absorption", which they define as the difference between the percentage transmission and 100 per cent. The percentage transmission gives a readily comprehended figure, but it must be remembered that if two waters transmit, say, 80 and 40 per cent. per metre, the percentage reaching say five metres will not be in the same 2 : 1 ratio, but in that of $(0.8)^5 : (0.4)^5$. The transmissive exponent is useful because it enables one to compare light at different depths; thus when $\mu = 0.2$ there is the same amount of light at, say, 20 metres as there is at 10 m. when $\mu = 0.4$, and at 40 m. when $\mu = 0.1$.

According to data from the Smithsonian Institution the percentage of the total radiation found at the earth's surface between 300 and

Table 10.

Transmission of light of various wave-lengths by Wisconsin lakes.

D and *C* as in Table 9. *T*, depth in metres to which total radiation measurements were carried. Angle of refraction, *r*. Transmission is the percentage of normally incident radiation passing through a 1 m. thickness of water, the values given are averages over the depth studied. Transmission for yellow was obtained by subtracting the readings for red from those for the yellow filter, which includes red. ? denotes too small to measure. In every case the reading at 1 m. is taken as 100, so that infra-red has been almost entirely filtered out by this water layer. μ, calculated from the transmissions given by Birge and Juday.

Lake	Date 1929	Tm.	Dm.	C.	Cos r.	Transmission %					μ				
						W.	B.	G.	Y.	R.	W.	B.	G.	Y.	R.
delaide	29/8	5	2.7	35	0.88	35	12	32	40	35	1.05	2.12	1.14	0.91	1.05
ig Carr	13/7	8	7.6	0	0.94	65	59	..	76	57	0.43	0.53	..	0.28	0.57
lear Crooked.	19/8	9	4.3	16	0.84	57	45	62	67	52	0.57	0.79	0.48	0.40	0.65
rystal	7/8	15	11.2	0	0.90	81	81	85	84	68	0.21	0.21	0.16	0.17	0.38
rystal	23/8	19	12.2	0	0.90	83	82	86	84	67	0.19	0.20	0.16	0.17	0.40
ishtrap	18/8	6	2.6	22	0.90	37	15	31	42	34	0.99	1.90	1.17	0.85	1.08
elen	2/7	3	1.7	88	0.95	24	2	..	10	23	1.43	3.91	..	2.30	1.47
ohnson	30/7	7	3.7	18	0.90	58	42	60	66	47	0.54	0,85	0.51	0.41	0.75
ittle Pickerel	19/7	2	1.4	132	0.85	8	?	..	?	8	2.52	?	..	?	2.52
ary.....	29/8	2	2.1	118	0.85	16	0.4	9	10	18	1.83	5.52	2.40	2.30	1.71
idge	15/8	3.5	2.9	58	0.87	24	2	..	22	28	1.43	3.91	..	1.51	1.27
uskellunge..	18/7	10	4.4	6	0.88	60	55	64	68	52	0.51	0.65	0.45	0.38	0.65
apoose	15/8	9	5.3	20	0.85	58	41	64	64	51	0.54	0.67	0.45	0.45	0.67
ar.....	26/8	13	8.1	0	0.86	74	67	74	79	61	0.30	0.40	0.30	0.22	0.49
rout.....	6/8	12	5.0	6	0.92	59	53	68	68	55	0.52	0.63	0.38	0.38	0.59
urtle	5/7	4	1.9	69	0.85	23	1.5	..	23	19	1.47	4.20	..	1.47	1.66
eber.....	23/8	14	6.9	0	0.83	75	75	84	81	63	0.29	0.29	0.17	0.21	0.46
ild Cat	29/7	5	2.5	26	0.83	34	17	..	39	34	1.08	1.77	..	0.94	1.08

764 mμ, with air mass 1, (viz. with the sun at the zenith) and precipitable water 0.5 cm. is about 57.5; with air mass 5 and water 2.5 cm. it is 32.6 per cent. and all intermediate results may be found as these two variables are given different values. This, of course, refers to direct sunlight only, the scattered light from the sky tends to keep the percentage more nearly constant for the lower altitudes of the sun.

With air mass 1.5 and water 2.0 cm. the value of the radiation in the region named is about 55.7 per cent., this, rounded off to 56 was taken in comparing results with those of others who measured light only. Solar radiation which has passed through one metre of pure water has lost practically all radiation of greater wave-length then 764 mμ. If the absorption coefficients of Aschkinass be taken, 1—2 per cent. of the radiation remaining at 1 m. may come from the region between 764 and 850 mμ. Taking the value given by Nichols in the Smithsonian Physical Tables (p. 307) for 779 m. no appreciable part comes from this region. Thus the measurements of radiation made at 1 m. may be considered as practically all[1]) in the form of visible waves, as defined above, including ultra-violet able to penetrate the glass; the plate glass probably lets but little through below 370 mμ. It follows that, since of the total radiation rather more than half is light, the percentage of the radiation at any depth may roughly be doubled to show the penetration of light as a percentage of that in air.

In their most recent work (1931) Birge and Juday have used the Moll thermopile with Jena glass filters of the GG., OG. and RG. series, together with Wratten No. 88a for infra-red. The glasses of these series cut off sharply and transmit very freely all radiation of longer wave-length than that cut off. In general the readings of the filters were plotted at the wave-length where the line of the cut-off intersects the 50 per cent. line of the transmission diagrams. This placed the filters as follows:—

Filter			mμ	Filter			mμ
GG. 1	(7)	(7)	350	OG. 1	(5)	—	525
GG. 2	—	(6)	375	OG. 2	(4)	—	570
GG. 3	—	(5)	425	R.G 1	(3)	(1)	615
GG. 5	—	(4)	450	RG. 2	(2)	—	625
GG. 7	—	(3)	460	RG. 5	(1)	—	670
GG. 11	(6)	(2)	490	W. 88 a			750

The mean value of readings with RG. 1 and RG. 2 was plotted at 620 mμ. GG. 1 was taken as transmitting 100 per cent., since its readings

[1]) With a specially red-sensitive photo-electric cell it appears that this small amount of infra-red may introduce an appreciable error; at 1.5 or 2 m., however, this would be insignificant.

were close to those with no filter; by this the necessity of attempting to correct for the glass is removed. The first column of figures in brackets shows the order in which the filters were used in carrier-plate No. 1; the second column that in plate No. 3. It will be noticed that each includes GG. 1, GG. 11, and RG. 1 to connect the two parts of the colour series. The eighth opening was filled by an opaque disc, with which the readings began and ended. The arrangement was such that normally the readings increased in each set.

During the work in the summer of 1930 but few readings were made below 10 m. Even where greater depths could be reached in the more transparent lakes, observations were rarely carried below the epilimnion, since the delay of 5 minutes to allow the apparatus to cool was serious when so large a number of readings had to be taken for the various colour-filters. The summer was a very favourable one, as it gave many days with clear sunshine or with clouds only between 10 a.m. and 3 p.m. As before, the presence of diffuse light has been neglected, but in the blue at least this constitutes a considerable proportion of the total. The effect of this would be to make the angle of incidence more oblique[1]) and so lengthen the path in the water required to reach any given depth, but the error involved does not appear to be serious and, as mentioned previously, to attempt to define the angular distribution of the light is hopeless. For the many interesting details of these researches the original papers should be consulted, but a summary of the results is given in Table 11.

Photo-electric Measurements under Water.

The pioneer investigations of Shelford and Gail (1922) in the Puget Sound have been summarized already in the previous review (1926). It may be remembered that they used a gas-filled cell, sensitive to blue light only, together with a galvanometer and worked down to 120 m. as a maximum. A number of papers dealing with photo-electric photometry have since been published by Shelford alone or with Kunz (1926, 1929, 1930). The cells are used without a cover of any sort and attention has been paid to designing the form which gives a reading which is most accurately independent of the angle of the incident light, and to their calibration. Of all the forms tried the collapsed-sphere cell, which presents a convex sensitive surface, is said to be the most practical form for general ecological work and for the measurement of sunlight, including continuous recording. Such a cell can easily be covered with special filters of spherical curvature. They recommend the use of large cells capable

[1]) But see the evidence; from photo-electric measurements at sea, where the altitude of the sun appears to the without effect upon μ_D.

Table 11.

Variation of distribution of radiation with increase in depth. The columns *V* to *R* show percentages of total visible radiation found in each colour. *C* denotes colour of water.

Lake	m	V.	B.	G.	Y.	O.	R.
Crystal $C = 0$	1	18	16	15	18	18	15
	3	16	22	20	22	12	8
	5	16	20	27	23	10	4
	7	14	25	27	23	10	1
	9	14	24	30	24	8	..
Day $C = 0$	1	14	20	16	20	15	15
	3	13	20	21	24	14	8
	5	11	21	25	26	13	4
	7	8	22	30	27	13	..
	9	5	21	38	29	7	..
Black Oak $C = 10$ ..	1	11	19	16	20	18	16
	3	9	14	21	29	18	9
	5	5	15	24	33	17	6
	7	2	16	25	37	17	3
	9	..	5	25[1])	34[2])	16	..
Silver $C = 11$.....	1	12	18	19	17	18	16
	3	11	15	21	25	18	10
	5	7	17	24	31	17	4
	7	3	17	29	36	13	2
Edith $C = 9$.....	1	11	17	14	21	19	18
	3	10	16	20	23	19	12
	4	9	15	22	30	17	7
	5	7	16	29	33	11	4
White Sand $C = 18$	1	10	16	17	21	18	18
	3	5	7	22	33	20	13
Kawaguesaga $C = 16$	1	9	11	20	23	18	19
	3	5	9	22	32	21	11
	5	3	8	23	41	22	3
Midge $C = 29$	1	4	10	12	22	24	28
	2	..	7	13	24	39	17
	3	..	3	9	30	39	19
Adelaide $C = 34$	1	..	11	13	26	24	26
	3	..	4	14	28	35	19
George $C = 40$.....	1	3	7	14	23	26	27
	3	..	3	11	30	32	24
Tenderfoot $C = 49$ ..	1	..	9	17	19	25	30
	3	..	5	9	26	40	20
Little Papoose $C = 36$	1	3	9	11	29	20	28
	2	..	7	17	22	26	28
	3	..	4	20[3])	25[4])	28	33
Little Long $C = 105$	1	..	5	6	14	32	43
	2	..	3	5	4	32	56
Mary $C = 123$	1	..	3	3	12	28	54
	1.5	..	..	2	8	35	55
2 m. computed	2	..	..	..	5	40	55

[1]) ? 35. [2]) ? 44. [3]) ? 14. [4]) ? 21.

of being used at 200 micro-amperes (μ *a*), with a direct proportionality limit of 250 μ *a*, so that there should be little or no variation in sensitivity within the ordinary working range of light and voltage. It may here be said that the gas-filled cell has not been found by other workers to be a really satisfactory instrument for quantitative measurements, beyond certain narrow limits; but with special precautions, to bring its sensitivity back to an approximately constant level, it can be used where, on account of very low illumination, the more desirable vacuum form is of inadequate sensitivity (Campbell and Ritchie, 1929, Atkins, 1931).

Shelford (1930) also states that only the very best (gas-filled) cells, used with much care, can be depended upon to repeat readings when giving a large current, 10—100 μ *a*. As regards vacuum cells, Shelford commends those of Case and of Burt, which he states show a direct proportionality between light intensity and current over a wide range of readings. A test is quoted in which a Burt cell was used by the General Electric Co. of U. S. A. for sunlight recording for eight months with no change in sensitivity. The experience of Atkins and Poole has also been favourable to this cell and to the vacuum cells of the General Electric Co., England. The writer's view is that for quantitative work a gas-filled cell should only be used as a last resort.

A few measurements were carried out by Shelford and Kunz (1926) upon Lake Mendota using potassium, rubidium and caesium gas-filled

Table 12.

To show the percentage of light of different colours transmitted by the surface waters of Lake Mendota on the afternoon of June 13, 1925.

The first metre is designated 1 and so on. The figures have been calculated to vertical penetration (apparently assuming pure sunlight as the source). Duplicate figures are calculated from two metre intervals.

m	Potassium		Rubidium		Caesium		
	Clear	Blue D.	Clear	Noviol C.	Clear	Noviol A.	Yellow
1	47.5	35.4	37.2	47.2	41.2	45.2	63.6
2	33.0	25.5	39.7	44.5	48.3	36.0	65.7
3	43.4	37.8	43.8	47.0	55.3	45.9	68.5
4	43.2	47.7	39.9	54.2	63.3	57.8	70.6
5	43.0	46.1	60.9	56.1	72.2	57.3	70.0
6	47.4	63.4	63.3	62.2	81.5	61.5	..
7	(60.7)	60.0	77.0	76.9	(79.7)	..	..
8	60.7	69.3	83.6	68.3	79.7	..	..
9	(65.8)	(56.8)	(75.8)	58.8	(76.5)	..	..
10	65.8	56.8	75.8	62.7	76.5	..	..

cells together with light filters; "blue D" with potassium cell gave a maximum sensitivity sharply at 450 mμ; "Noviol C" was used to restrict the rubidium cell to green and yellow light, the maximum sensitivity being, without filter, 470 and with filter 495 mμ; the caesium cell, both alone and with "Noviol A" had a maximum at 520 mμ, but with yellow filter it was at 550 mμ with low sensitivity, and at 595 mμ with red filter, but the sensitivity was then very low. Table 12 shows some of the results.

The work on the penetration of light of different colours was continued in Puget Sound (1929) using the equipment tested in L. Mendota. The results, being expressed in graphs, do not lend themselves readily to abstraction. The transmission is a maximum at 550 mμ, and appears to be about the equal at 600 and 430 mμ in one case and at 600 and 360 mμ in another, both in San Juan Channel, where the water was very much clearer than in Dolphin Bay. The measurements without filters were carried on down to 50 m., and to from 6 m., for red, to 8 for yellow and 50 m. for blue. In general the water was not as clear as it had been found to be in 1920.

Photo-electric measurements at sea.

For the measurement of the photo-electric current the potentiometer telephone method introduced by H. H. Poole (1925) has been used, with some modifications made in the light of experience. The apparatus can now be obtained from a London firm of instrument makers. The photo-electric current is measured by noting the drop in potential across a high resistance, using a telephone as a null-point indicator. The telephone circuit was interrupted many times a second by a clock-work interrupter. The interposition of a two stage amplifier increased the sensitivity, but the amplified current is not itself measured, since only the unbalanced portion is amplified and this is reduced to zero in the balancing operation.

Vacuum photo-electric cells were used for measurements of the air and under-water illumination, made in quick succession. These cells were mounted beneath a highly efficient diffusing surface so that the vertical component of the illumination from the sky and the sun were measured. These are denoted as V_a, for air, and V, for water, in the tables. In these β denotes the ratio of total illumination, thus defined, to diffuse illumination; the latter was obtained by screening off direct sunlight by a small disc held at a distance. The coefficient of absorption, or transmissive exponent, is denoted by μ_v, since the length of the path of the rays has been taken as the vertical distance, or depth.

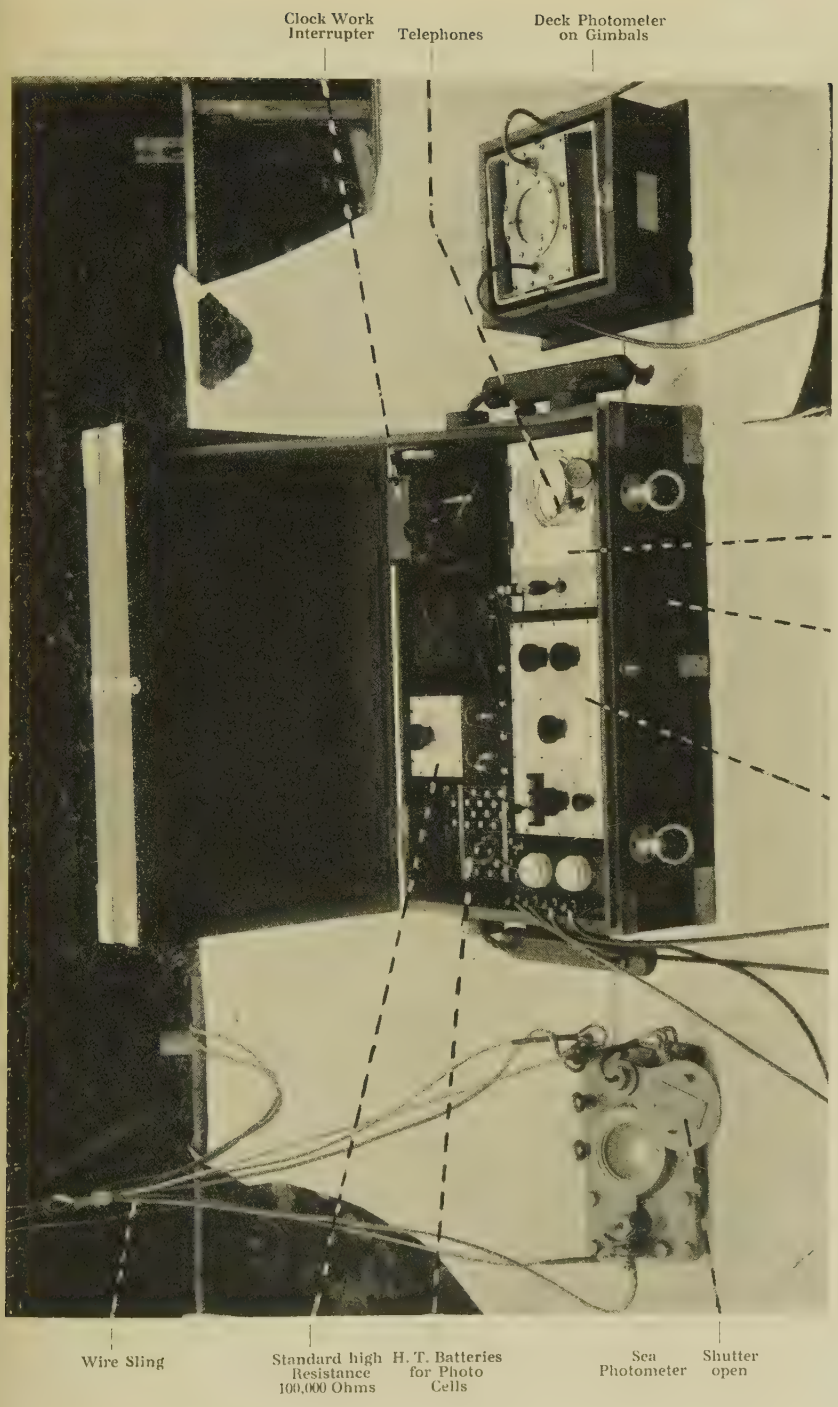
Clock Work Interrupter
Telephones
Deck Photometer on Gimbals
Amplifier
Sea Chest Metal Lined
Potentiometer
Cables to Photometers
Shutter
Wire Sling
Standard high Resistance 100,000 Ohms
H. T. Batteries for Photo Cells
Sea Photometer
Shutter open

Fig. 7.

For deeper water a gas-filled potassium cell was used. This was standardized against the vacuum cell on the roof, both in air and when submerged at the various depths at which the anode potential of the cell was raised or lowered to alter its sensitivity appropriately.

The vacuum cells were usually of potassium, though some series, including those with a filter transmitting ultra-violet only, were made with a Burt sodium cell. The colour filter work was rendered possible by the advent of the thin film caesium cell of the General Electric Co., England, type C. M. V. 6, as already described.

Some use has also been made of an integrating device introduced by J. H. J. Poole (1928) in which the rate of flashing of a small neon lamp is measured, since it is proportional under the conditions of the apparatus to the light intensity.

Measurements have also been carried out by a photo-chemical method. This, too, integrates the illumination over a period — but a much longer one — during which uranyl oxalate is being decomposed; the amount remaining in the tubes lowered to various depths is then ascertained by titration with permanganate.

Whilst the potentiometer method is the quickest to operate and the most delicate, the neon lamp is specially useful for situations in which the light is varying very rapidly, such as just below the surface. It is furthermore far less costly and more portable.

Fig. 7 shows the potentiometer apparatus in its latest form (Gall and Atkins, 1931) and Fig. 8 the neon lamp apparatus, without photometers attached, as assembled by Messrs. H. Tinsley & Co., London. Fig. 9 shows the lay-out of the potentiometer method circuit as used since 1928.

The potentiometer apparatus shown in Fig. 7 is in certain respects closer to the arrangement originally used, than to the later disposition of the instruments as in Fig. 9. The assembly of an entirely new outfit, designed for use on the U. S. A. Research Ship "Atlantis", rendered it possible to secure the better insulation required without removing amplifier and high-tension batteries from the sea chest. This was metal lined, and the potentiometer, amplifier and high resistance were all in metal cases. An electric heater was also included. This outfit was reported as having functioned satisfactorily throughout the passage of the Atlantic westwards, during which measurements were made down to 175 metres.

The photo-chemical method has been used but little (1930). It is well suited for comparative measurements in good illumination, but in weak light the oxalate destroyed is small in amount and titration has to be

Fig. 8. Neon discharge tube photometer. The terminals shown are, from left to right, negative, guard ring and positive.

carried out with the greatest care or the errors become serious. It follows that it is far less delicate than the electrical methods. It is sensitive to the ultra-violet, violet and slightly to the blue.

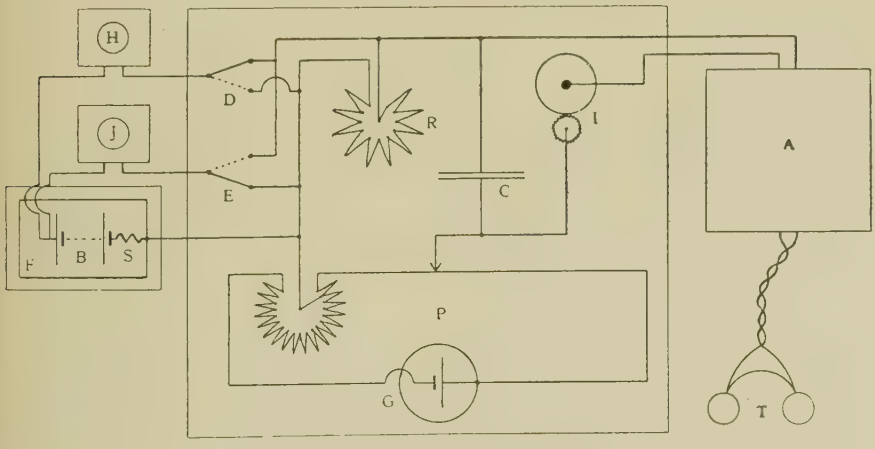

Fig. 9. Diagram of the potentiometer apparatus for photoelectric measurements at sea. *A*, amplifier; *B*, high tension batteries; *C*, condenser; *D* and *E*, switches; *F*, metal box insulated from outer wooden one; *G*, guard plate, on which stands potentiometer accumulator; *H*, vacuum photo-electric cell in deck photometer; *I*, interrupter; *J*, vacuum or gas-filled photo-electric cell in submarine photometer; *P*, potentiometer; *R*, 100,000 ohm resistance, sub-divided; *S*, 10,000 ohm safety resistance; *T*, telephone. The batteries and amplifier were included in the main sea chest in the original and final forms of the apparatus.

The solution used was 0.1 N with respect to oxalic acid and approximately 0.01 M with respect to uranyl sulphate $UO_2SO_43H_2O$. After exposure of the solution in quartz or glass test tubes the amount of unchanged oxalic acid is determined. The method is obviously one which integrates the change — and so the illumination — over the period of exposure. Measurements were made down to 40 m. though usually 20 m. was the limit. The value of the coefficient of absorption (transmissive exponent) varied from 0.095 to 0.217 in the English Channel, Station E 1. The tubes were lowered from a line attached to a spar, which was then allowed to float right away from the ship, so as to avoid error due to shadows. The ratio of the photo-chemically determined coefficients to the photo-electrically determined values (obtained with potassium vacuum and gas-filled cells) varied from 1.02 to 1.37. The former, however, measured light received by a tube, the latter that falling on a horizontal plate.

Outline of the neon lamp method of photometry.

This has been described by J. H. J. Poole (1928), who first devised it and the apparatus is shown schematically in Fig. 10. The wooden box containing the condensers, neon tube and safety resistance is indicated in section.

The ordinary photo-electric circuit is used to charge a condenser, or, in practice, one of a set of four, of capacities, 0.5, 0.05, 0.005 and 0.0005 micro-farad (μF), any one of which can be used by making connection with a wander plug. A neon lamp is connected in parallel with the condenser. Provided the voltage across the lamp is adequate, a flash will appear from time to time, the condenser being partially discharged thereby. It has been shown that the rate of flashing is proportional to the charging current, namely to the mean value of the illumination over the period. A sufficient potential, V_1, should be connected to the guard ring, not shown in figure, attached to the neon lamp to overcome the effect of small leaks; otherwise a current due to a certain number of metre-candles would be required merely to overcome the leakage. Usually the total potential, V_1 plus V_2, should be 230—240 volts, as the potential across the photo-electric cell P must always be in a region in which it is near its saturation point.

The effective capacity of the apparatus may differ considerably from the nominal capacity in parallel with the neon lamp, for the leads themselves have a capacity which is by no means negligible in the case of the submarine cable.

By this method Poole and Poole (1930) measured the penetration

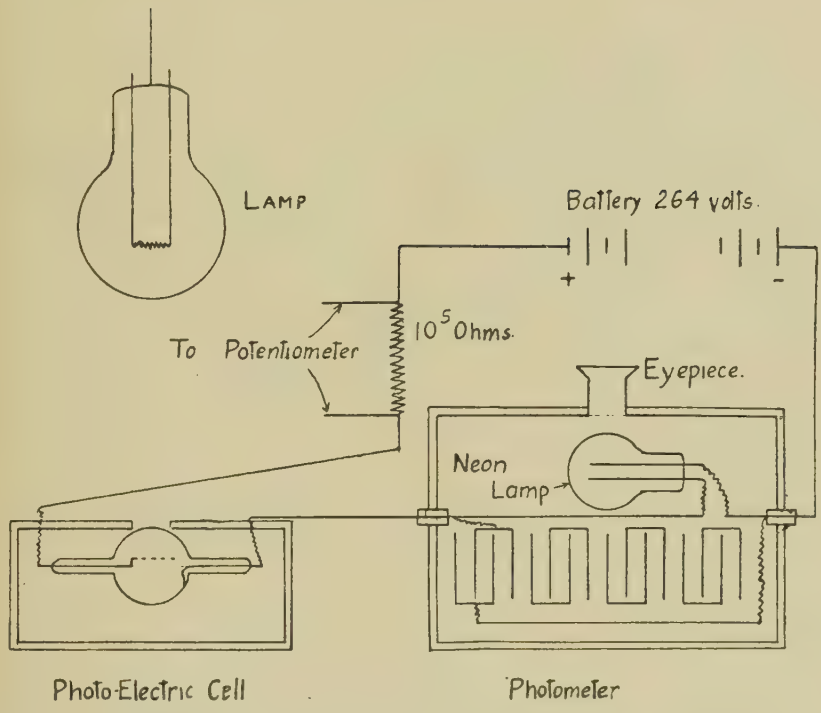

Fig. 10. Neon discharge tube photometer, as described in text. The suspended lamp and leads to potentiometer were only used in initial calibration.

of light into Lough Bray, Co. Wicklow. This lake is at an altitude of about 300 metres above sea level. The water is at about pH 4.8 and is stained deeply with peat. Phytoplankton is almost entirely absent. Measurements were made from a small boat, moored in a part of the lake where the depth is about 40 m. A Burt sodium cell, under opalized glass, was used for the under-water measurements and a G. E. C. sodium cell, both vacuum, for measurements in air. The results are given in Table 13.

The enormous value of μ_v for the first metre — about 50 times that for sea water — is almost certainly due to the deep brown colour of the water, which very rapidly absorbs the blue, violet and ultra-violet waves to which the cell is sensitive. The longer waves near the limit of sensitivity of the cell, which is in the neighbourhood of 500 mμ, penetrate rather deeper, so that μ_v decreases with increase in depth. The white window of the photometer was just visible at 1.75 m. In clear sea water it would probably be visible to at least 10 m., but the relative opacity of the water compared with sea water is evidently not nearly so great when judged visually. These values may be compared with those

Table 13.

Percentage illumination at different depths and mean vertical absorption coefficient, μ_v for each successive depth in Lough Bray, Ireland.

Measurements made between 2.30 and 4 p.m., G.M.T., on August 26th, 1929. There was a bright sun and strong westerly wind. Cell sensitive to ultra-violet, maximum 360 mμ, also violet and blue. The surface loss was taken at 15 per cent. in calculating the 0—1 metre value of μ_v, entered opposite 1 m. and similarly onwards.

m	Percentage	μ_v
0	100	..
1	0.5	5.1
2	0.035	2.6
3	0.01	1.25
4	0.00	..

found by Birge and Juday for L. Mary, namely, $\mu = 5.5$ and 2 m. for the disc.

The method of standardizing the neon tube apparatus, so as to obtain values for the illumination, will be clear from inspection of Table 14. As already pointed out, the effective capacity is compounded of that of the condenser and photo-electric cell with cables. This lessens the sensitivity of the method for work in the sea, but does not impair its usefulness for the lesser depths. The apparatus used on the "Atlantis" could probably be used to a very considerable depth since the large photo-electric cells gave a current several times as great as any used at Plymouth. The compound capacity may be denoted thus:— AM, capacity of A (0.5 μF) with that of the submarine photometer M, including its leads; BH, capacity of B (0.05 μF) with that of the deck photometer H. The latter contains a vacuum potassium cell, the former a vacuum sodium cell. In practice the time taken for a convenient number of flashes is measured; from this we can find either the time (t) of a single flash, which is inversely proportional to the current, or the number of flashes per minute (n) which is directly proportional to the current. The standardizations shown in Table 14 took one hour under conditions of steady illumination and would have taken longer with variable light or at sea.

The apparatus was afterwards used at sea and the surface loss determined with it:— Series N1, 15.5 per cent.; N3, 7.5; N4, 10.5; with potentiometer apparatus, Series 48, 15.5; 50, 16.5; mean 13.1.

In obtaining illuminations below the surface the readings must be multiplied by the factor 0.935, which is the ratio for the light in air to the light just below a smooth water surface, for diffuse daylight.

Table 14.

Standardization of neon lamp apparatus.

September 29th, 1929. On flat roof of Laboratory, Plymouth, with photometers *H* and *M* side by side on parapet. *H* was used with potentiometer to determine vertical illumination, *V*, shown in thousands of metre candles, k.m.c., carbon arc standardization. When *H* was attached to neon tube apparatus, *M*, previously standardized against *H*, was used with the potentiometer. Number of flashes per minute = *n*. The window of *M* was wet, as used at sea. Voltage was 150 on neon tube apparatus, usual 60 v. with potentiometer cell. The series given are the means of five, four, five and six highly concordant determinations respectively.

G.M.T.	V, k.m.c.		V, k.m.c. per flash per min.	Ratios of Sensitivities
				$\frac{AM}{AH}$
		n AM		
3.10—3.24	40.58	17.6	2.31	11.0
				$\frac{BH}{AH}$
		n AH		
3.25—3.46	35.18	1.38	25.50	12.4
				$\frac{BM}{BH}$
		n BH		
3.47—3.59	32.20	15.7	2.06	8.2
				$\frac{BM}{AM}$
		n BM		
4.0 —4.10	27.35	108.9	0.251	9.2

The submarine photometers were standardized in air, with opal glass in position and window wet, bubbles being excluded. The light in air was measured by the deck-house roof photometer, H. Accordingly the "air" reading of the submarine photometer corresponds to an illumination in the layer of water just outside its window only 0.935 times what one assumes for the purpose of standardization. The factor is an approximate one for an assumed uniformly bright sky. This correction has been made in obtaining the results in all tables given by Poole and Atkins.

The results obtained at sea with the potentiometer method.

Measurements were made, in quick succession, of the illumination on the deck-house roof and of that just above the water surface, just below it and at depths of 1, 5, 10, etc., down to 70 metres. The loss at

Table 15.

Photo-electric measurements in the open sea.

Series 29. May 7, 1928.

Vacuum potassium cell in photometer in air, and gas-filled potassium cell in submarine photometer. At E l. Very light air from *N*. Scarcely any swell, sea glassy. Sky hazy with light clouds and hot sun. Secchi disc 17 m. in shadow on weather side of ship at 2.58 p. m., 19 m. in sun on lee at 3.4 p.m. (V_a = 71 k.m.c.), 14 m. to windward at 4 p.m. and 22 m. to leeward at 4.5 p.m., with overcast sky (V_a = 18.7 k.m.c.). Results with asterisk calculated from an assumed surface loss of 15 per cent. *r* denotes photometer on deckhouse roof, *a*, swinging above water, *b*, photometer just below water surface.

The value of μ_v at 5 m., for example, has been calculated over the range 0—10 m., and so on.

Series 29.

G. M. T.	$\alpha°$	Light.	β	d	V_a	V	p	μ_v
11.13 a.m.	55	Sun, hazy sky	2	r	77.0	77.0	100.0	..
11.29 —	56	—	—	a	84.5	76.5	90.5	..
11.32 —	—	—	—	b	86.5	64.5	74.5	..
11.46 —	57	—	—	5	85.5	40.5	47.5	0.097*
11.52 —	—	—	—	10	85.5	27.6	32.3	0.070
11.56 —	—	—	—	15	84.0	19.5	23.2	0.083
12.2 p.m.	—	—	—	20	84.5	12.0	14.2	0.099
12.14 —	—	—	—	25	84.5	7.3	8.65	0.101
12.25 —	—	—	—	30	83.0	4.25	5.15	0.099
12.29 —	—	—	—	35	84.5	2.72	3.22	0.104
12.35 —	—	—	—	40	84.0	1.53	1.82	0.122
12.56 —	56	—	—	45	84.0	0.80	0.955	0.100
12.59 —	—	—	—	50	82.5	0.55	0.670	0.091
1.13 —	55	—	—	55	85.0	0.327	0.385	0.111
1.21 —	—	—	—	60	84.0	0.185	0.220	0.085
1.28 —	54	—	—	65	85.0	0.139	0.164	0.060
1.34 —	—	—	—	70	84.5	0.102	0.121	..
1.41 —	53	—	—	55	81.5	0.277	0.340	..
1.46 —	—	—	—	50	82.0	0.445	0.540	..
1.55 —	52	—	—	40	82.0	1.42	1.73	..
2.34 —	47	—	1.5	20	76.0	10.45	13.8	..
2.49 —	45	Cloudy	1.0	r	53.5	53.5	100.0	..

Series 45.

Jan. 2, 1929. Vacuum photometers. At E l. Strong N. E. wind. Waves breaking everywhere. Very heavy swell. Cloudy sky, light very variable.

12.53 p.m.	..	Cloudy	1.0	5	15.0	6.3	42.0	0.127*
12.45 —	..	—	—	10	12.45	2.98	23.9	0.101
12.52 —	..	—	—	15	13.7	2.10	15.3	0.097
12.59 —	..	—	—	20	15.25	1.39	9.1	..

Series 46.

Jan. 2, 1929. Gas-filled cell in water. Other conditions as in Series 45.

1.27 p.m.	..	Cloudy	1.0	r	7.15	7.15	100.0	..
1.34 —	..	—	—	5	7.65	2.66	34.8	0.138*
1.47 —	..	—	—	15	9.4	1.01	10.7	0.106
1.52 —	..	—	—	25	7.45	0.315	4.25	0.082
1.54 —	..	—	—	35	7.5	0.156	2.08	..

the surface varied very considerably, from about 5 to 30 per cent. In every case a set of measurements was taken, the averages of the individual results being used to calculate the illumination from the known constants of the photometers. These were standardized in daylight against a vacuum potassium cell which had been standardized against a carbon arc of known candle power. This source was chosen as being the nearest to daylight in spectral composition; though in future it is hoped to re-standardize the cells in terms of "mean noon sunlight" as defined, from ABBOT's data, by the Seventh International Congress of Photography.

The method of working will be clear from Table 15, showing the results of Series 29, 45 and 46; the observations were made at International Hydrographic Station E1, about 20 miles off Plymouth and 10 miles S.W. of the Eddystone.

The columns denote Greenwich Mean Time; altitude of the sun; natural lighting; β — the ratio of total to diffuse light; depth in metres; vertical illumination in air, V_a, expressed in k. m. c., V, the same in water; p, the percentage of light in water and μ_v the absorption coefficient for light assumed to traverse a path equal to the depth. The angle of the resultant beam in the water is probably not far from 60° with the vertical.

In general it may be said that in the region of E1, the light that penetrates the water is reduced to roughly one-half of its initial value each five metres or if the water be specially clear, as it was in the series quoted, to about two-thirds. This refers, of course, to blue light to which the potassium cell is sensitive.

Photo-electric measurements of the penetration of light of different wave-lengths.

In Table 16 are shown the percentage values of the sub-surface light for various wave-lengths as calculated from absorption coefficients determined with type C. M. V. 6 cell and colour filters. The values assigned to the mean wave-lengths are, of course, approximations for those which are cut out heavily by the water, since the true mean value naturally varies as the components are selectively absorbed.

It may be seen from Table 16 how heavily the red and ultra-violet ends of the spectrum are cut out. They are, however, mainly acted on by different agencies. The red is absorbed by the water itself, whereas the longer ultra-violet is transmitted freely by the water, but is scattered by small particles in suspension. The shorter ultra-violet is even more affected by scattering and is also reduced in intensity by the sulphates of magnesium and calcium in the sea water (HULBURT, 1928).

Table 16.

Penetration of light of different colours.

Showing calculated percentages of the sub-surface light for values of μ_v corresponding to mean wave-lengths, approximately 760, 700, 660, 580, 520, 440 and 360 mμ, at various depths.

m.	$\mu_v = 0.567$	0.480	0.435	0.164	0.155	0.140	0.392
0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
1	56.8	61.9	64.7	84.9	85.6	86.9	67.6
2	32.3	38.3	41.8	72.0	73.3	75.5	45.7
3	18.3	23.7	27.1	61.2	62.7	65.6	30.9
4	10.3	14.7	17.5	52.0	53.7	57.0	20.8
5	5.92	9.08	11.3	44.1	45.9	49.5	14.1
6	3.36	5.62	7.33	37.5	39.3	43.0	9.53
7	1.91	3.48	4.74	31.8	33.6	37.3	6.45
8	1.09	2.15	3.07	27.0	28.8	32.4	4.36
9	0.618	1.33	1.98	23.0	24.7	28.1	2.94
10	0.346	0.826	1.28	19.5	21.1	24.4	1.99
15	0.020	0.075	0.148	8.56	9.84	12.2	0.279
20	0.001	0.007	0.017	3.77	4.51	6.08	0.040
25	..	0.001	0.002	1.66	2.09	3.02	0.006
30	..	..	..	0.732	0.958	1.50	0.001
40	..	..	..	0.142	0.204	0.370	..
50	..	..	..	0.028	0.043	0.091	..
60	..	..	..	0.005	0.009	0.022	..
70	..	..	..	0.001	0.002	0.005	..
75	..	..	..	..	0.001	0.003	..
80	..	..	..	..	..	0.001	..

Seasonal changes in the clearness of the water.

When the first extensive series of measurements with the blue-sensitive potassium cell, carried out in September, were extended into the winter, a great clearing of the water was observed. This was thought to be due to the reduction in the plankton. In spring, however, when the phytoplankton outburst was at its height, the water at Station E 1 was found to be clearer than ever previously observed, due apparently to movement inwards of water from about 20 miles further out. A study throughout the year showed that at E 1, the mean values of the percentages of the light in air reaching 20, 40 and 60 m. were 6.6, 0.72 and 0.085 respectively; for depths 0—20, 20—40 and 40—60 metres the mean values of μ_v were 0.150, 0.120 and 0.111.

It was found that, under the isothermal and homogeneous water conditions obtaining during the first half of October, the vertical absorption coefficient, μ_v, varied at E 1 from 0.146 in 1925 to 0.104 in 1927; 1928 and 1929 were intermediate with $\mu_v = 0.124$ and 0.139 respectively,

over the range 5—35 metres. Between 0 and 25 m. the ratio of the light falling on a vertical diffusing surface to that falling on a similar surface set horizontally was found in one series to be 0.31, as determined with a sodium cell.

From the foregoing one can form a general idea of the percentage illumination likely to be found at any particular depth, also of the colour composition of that light. When the daily light records have been worked up a knowledge of the seasonal variations will be available, in addition to the data from photographic measurements already carried out and to those obtained by AURÉN (1930) with a gas-filled cell. These and all physiological applications of the measurements must be held over till another paper.

In conclusion I wish to express my thanks to the Royal Dublin Society for permission to reproduce three figures and to the Marine Biological Association for similar permission and for the loan of the blocks for the plates.

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The Snellius Expedition.

By

P. M. van Riel.

In Volume V, No. 3, 1930, of this Journal, Professor VAN EVERDINGEN has already given some extracts from the reports of the Expedition to inform the readers of the "Journal" about the work carried out by the Snellius Expedition in the Dutch East Indies during the first and second cruise. Now that the last cruise is finished and more preliminary results are known this communication may be concluded.

In mid-August we left Surabaia for the last time and investigated in succession the Banda Sea, the southern part of the Molucca Sea, the Halmahera Sea and the Ceram Sea. After having made additional oceanographic observations in the Savu Sea, we investigated once more the adjacent region of the Indian Ocean in order to be better informed about the configuration of the sea-bottom and the connection between the deep Java and Timor Trench. Herewith our task in the Archipelago has been accomplished.

It was possible to carry out the oceanographic investigations approximately according to the programme that had been fixed by me beforehand. This is largely due to the valuable co-operation of the personnel of the Royal Navy. On the annexed chart 1 the whole track of the ship has been indicated with the various stations where serial observations or wire soundings have been carried out (black dots among which the larger ones indicate the anchor stations). As the depth of the entrances to the various basins determines the properties of the sea water within, these entrances have been sounded more thoroughly. In connection with the scale and the distinctness of the chart, however, these parts of the track have not been drawn.

During 16 months a distance of about 33,700 sea miles has been covered. On this track 32,450 echo soundings have been made and plotted, after

corrections, on large-scale depth charts. It appears from these observations that the configuration of the sea bottom was in several places in the field of research more complicated than had been known hitherto and

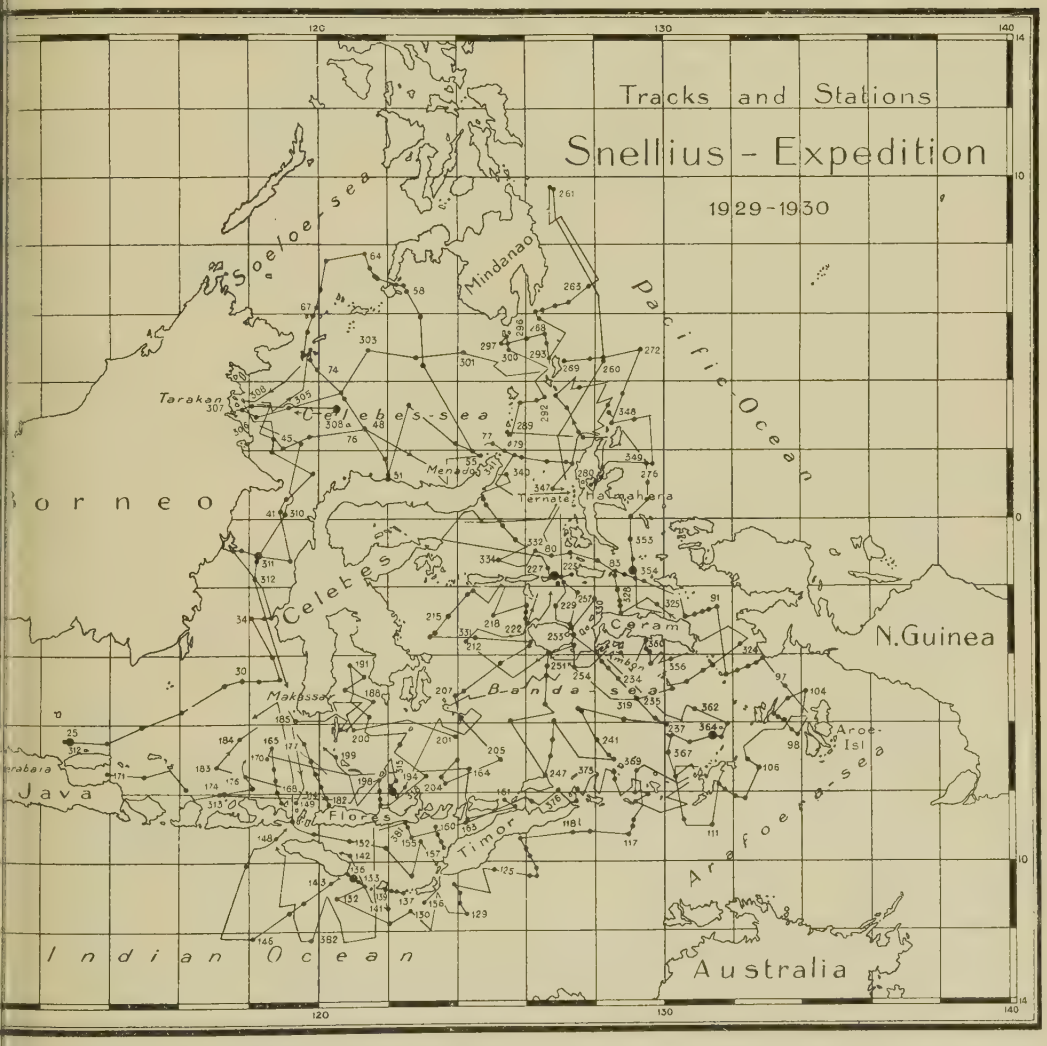

Chart 1. Tracks and Stations of the Snellius Expedition.

that the new depth chart will differ sensibly from the existing one. Especially in the Banda and the Ceram Sea important ridges have been found of which there was no previous indication.

When under way, approximately 2,000 samples of surface water have been collected and salinity and temperature determinations made. The

temperature of the surface, moreover, has been continually registered by a resistance thermometer, fitted outside the hull of the ship.

By means of serial observations at 373 stations the temperature has been measured between surface and bottom at approximately 8,000 points and at the same time an equal number of water samples from these levels has been collected and examined in the ship's laboratory. Including sur-

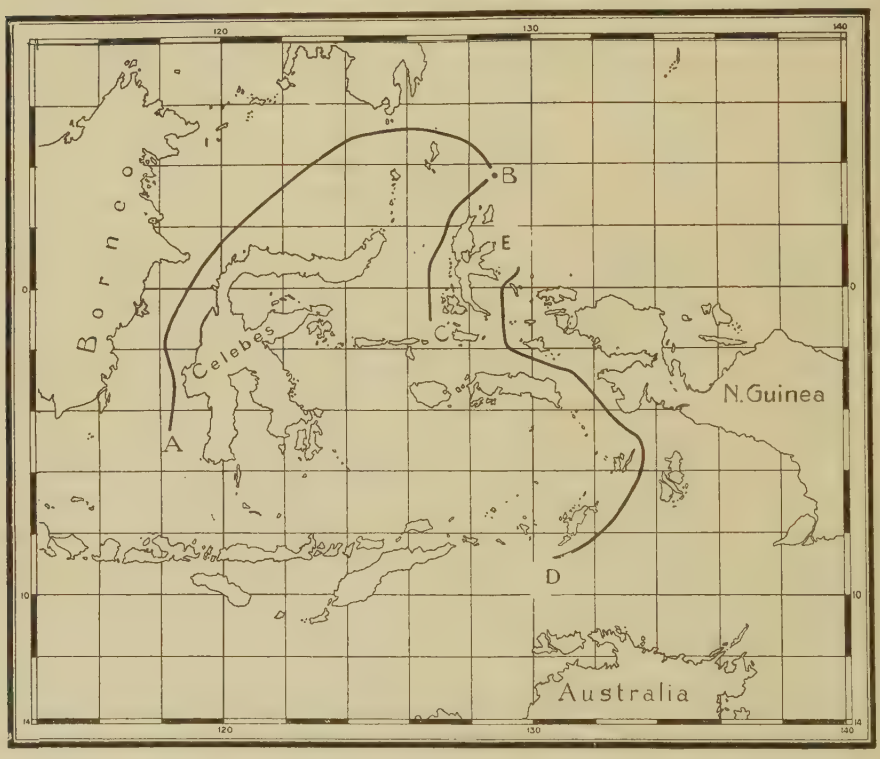

Chart 2. Lines along which the three vertical sections of fig. 1 have been plotted.

face samples, 10,000 and 5,000 samples have been titrated for salinity and oxygen respectively. The number of other chemical determinations amounts to nearly 7,000 (p_H, alkalinity, phosphates and H_2S).

At eight stations we anchored in the inland seas at great depths down to a maximum of 5,000 m., and on the sills between the deep basins, principally in order to obtain current observations (deepest layers 3,000 m.). Moreover, serial observations at the anchor stations have been repeated in the upper strata during more than 24 hours in order to study from temperature, salinity and oxygen curves the fluctuations caused by internal disturbances.

Plankton samples have been collected from the surface and also from deeper layers at nearly every station and under way between the stations.

A great number of coral samples and animals has been collected from the reefs and the beaches.

The wire soundings produced 282 bottom samples, the maximum length of which amounted to 206 cm. The greatest depth from which a sample has been obtained is more than 10,000 m. (Mindanao Trench, 9°40′ N. Lat.).

The ordinary meteorological observations have been made and, in addition to these, observations of humidity and the sun's radiation.

Owing to the zeal of the naval personnel the correction and the plotting of the large number of soundings on large scale charts has been done for the most part on board during the cruise. These charts are now being used in the preparation of a new depth chart on a scale of 1:2.5 millions (mercator projection) of the region between lat. 10° N. and 13° S. and long. 115° and 135° E. The working up of the oceanographic, geological and biological material will occupy several years.

To the preliminary results which have already been published in volume V, we may add some interesting facts about which nothing was known till now. One of the questions to which much attention has been paid during the Snellius Expedition is the interchange of water between the inland seas and both oceans. As far as concerns the Pacific Ocean a short communication will be given below, based on the salinity distribution in three vertical sections, along which the interchange of water with the Pacific Ocean is possible (chart 2, lines A B, C B and D E.)

The Pacific water contains a layer of high salinity between 100 and 200 m., which is characteristic of the equatorial current. This current runs along the north coast of New Guinea to the west. East of the island of Halmahera we observed a maximum salinity of about 35.4 $^{0}/_{00}$ in 150 m. (station 335). According to the salinity distribution at 14 stations between the surface and a depth of 1,000 m. the isobaths of 34.5—34.9 $^{0}/_{00}$ have been drawn along the vertical section D E.

For the vertical sections A B and C B the observations of 17 and 6 stations have been used. From this salinity distribution some information concerning the water transport may be deduced.

Obviously the salty water of the equatorial current, running north of New Guinea, between 100 and 200 m. (see chart 1), turns, east of Halmahera, to the left, enters the Halmahera sea and runs through the Ceram sea to the east and south-east. The salinity gradually decreases but the influence of this current is felt at a distance of more than 1000 km. from

the Pacific between the Aroe and Kei Islands, where Pacific and Indian Ocean water of low salinity meet.

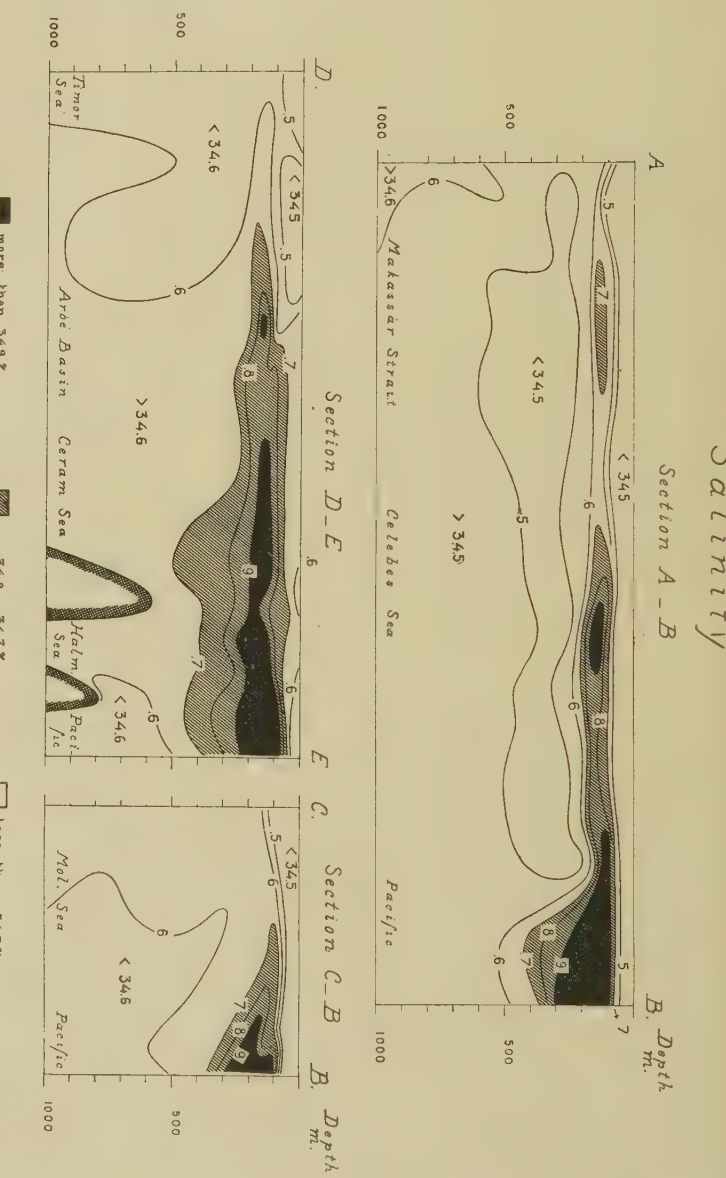

Fig. 1. Salinity distribution in three vertical sections, along which the interchange of water with the Pacific Ocean is possible.

A second important branch enters the Archipelago through the strait between the Talaud Islands and Mindanao (Section A B). In consequence we observed in the middle of the Celebes Sea in August a maximum salinity of more than 35.0 $^0/_{00}$ at 150 m., which decreases gradually to the

borders of this basin. Its influence is even felt in Makassar Strait between Borneo and Celebes.

The transport of salty water at 150 m. through the entrance between the Talaud Islands and Halmahera is of less importance (Section C B). Its influence does not reach farther than lat. 1° N. This is rather remarkable as we are concerned here with the widest entrance to the Archipelago. Nevertheless this passage remains very important, owing to the fact that the deepest sill, about 2,500 m., has been found here over which Pacific water may enter. And this depth determines, as already mentioned above, the properties of the water in the bottom layers of the deep basins.

The three sections show the great influence of the Pacific water on the tropospheric water masses of the Archipelago. The horizontal distribution of oxygen at 150 m. points to the same facts.

The serial observations below the level of minimum temperature showed interesting results, especially those in the Philippine Trench, east of Mindanao, where a minimum temperature has been observed at 3,500 m. instead of 5,000 m. as has been supposed hitherto. Obviously this trench forms part of a basin, separated from the open ocean by a ridge at a depth of less than 3,500 m. (the Bonin Ridge?).

In most layers below the level of minimum temperature of this trench and the inland seas stability calculations point to stable conditions, although the coefficient 10^8 E was so small that a slight alteration in salinity of a certain layer of about 0.02 $^0/_{00}$, which could be explained by inaccurate titrations, turned the scale for the corresponding layer to the other side.

That the renewal of the bottom water in deep basins with shallow sills is inadequate is betrayed by the values of oxygen content. This is for instance the case in the Sulu Sea, where the percentage of oxygen is far less than in the adjacent Celebes Sea, in consequence of the shallow sills at the entrances.

The renewal may be so bad that no oxygen is present in the deepest layers. This has been observed in the Kaoe Bay on the north-east coast of Halmahera. This bay has a maximum depth of about 500 m. and an entrance of not more than 50 m. deep. The unpleasant smell of the first bottom-sample hauled up betrayed at once the want of oxygen. The amount of oxygen appeared to be far less in the bay than outside the sill in the Pacific at the same level; the amount decreased rapidly with the depth and below the depth of 400 m. small amounts of H_2S have been observed instead of oxygen.

A Current-Meter, its Use and some Results.

By

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1. In consequence of a resolution of the International Council for the Exploration of the Sea, five ships, one each from Denmark, Finland and Sweden and two from Germany, made simultaneous measurements of currents and collected other hydrographical data in the Kattegat in August 1931. The results will appear in the International Hydrographical Bulletin. As the methods of current measurement have lately been under discussion at the meetings of the Council, and as the reports on the execution of current measurements in the sea and on their reduction are somewhat scanty, a short description of the details of the work carried out on our research-ship may provide some additional material for the discussion. The measurements were made from a ship at anchor at some 30 metres depth, and no attempt was made to determine the movements of the ship. The method used is what I have called the "comparative method" (1).

2. The Current-Meter employed registers direction and velocity on board. The principle on which it works was described in 1910 (2) and a more detailed description was given in 1923 (3). The first model was built in 1912.

The current-meter shown in fig. 1 hangs on a cable in which the two supporting insulated wires form the conductor for an electric current from the current-meter to a registering am-meter. The vital parts of the current-meter are enclosed in a watertight box, filled with petroleum and are visible through a glass cover (fig. 2). The velocity is indicated by a propeller with blades in the form of a screw. The direction of the current is determined from the angle between the axis of the apparatus, i. e., the direction of the current-vane, and the axis of the magnets in the box.

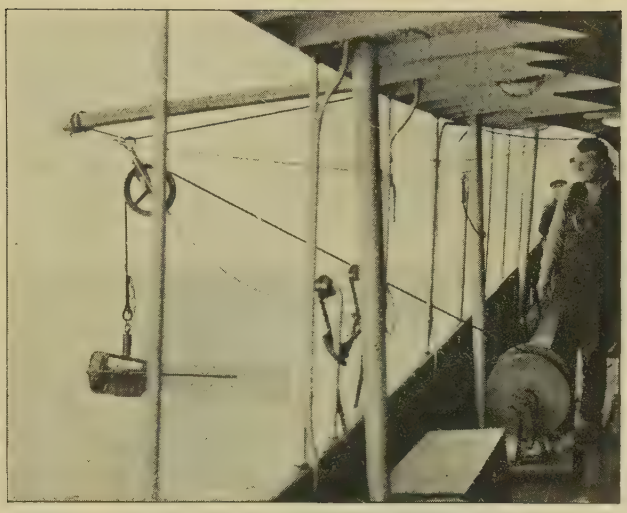

Fig. 1.

After 20 revolutions of the propeller the pin which supports the magnets is let down, the magnets fall and platinum knifes, placed underneath the frame of the magnets, make contact, one knife making contact with one of 36 circular segments, set compass-wise, to which one of the wires of the cable is connected, the other knives with a circular contact connected to the remaining wire, thus closing an electric circuit. Each of

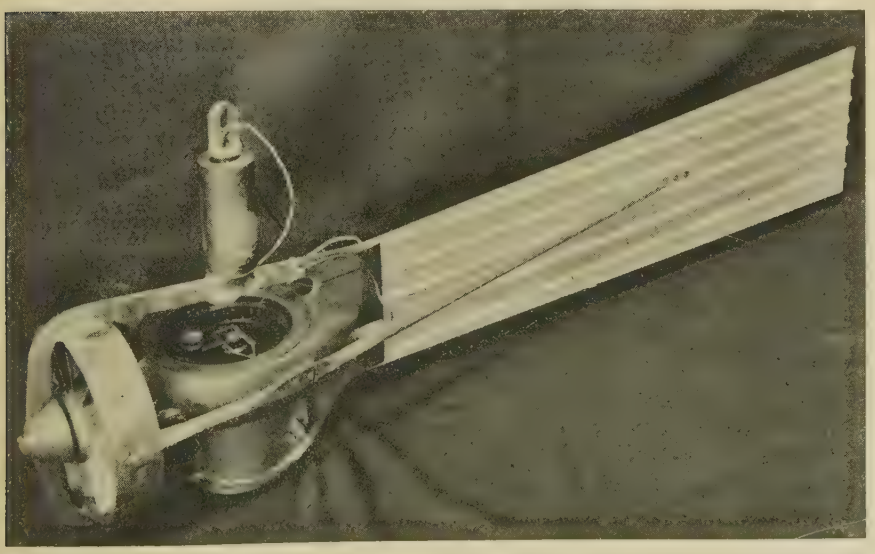

Fig. 2.

these branches has its own electrical resistance, including the circuit and additional constant resistances rising step by step from $33^1/_3$ to 1200 ohm. Using an electric current of 4 volts we get 10, 20, 30 .... 360 thirds of a milliampere for the directions 10°, 20°, 30° .... 360° of the current. An automatically registering ammeter, in which the paper is brought forward 1 mm. per second, and which is charged with paper sufficient to

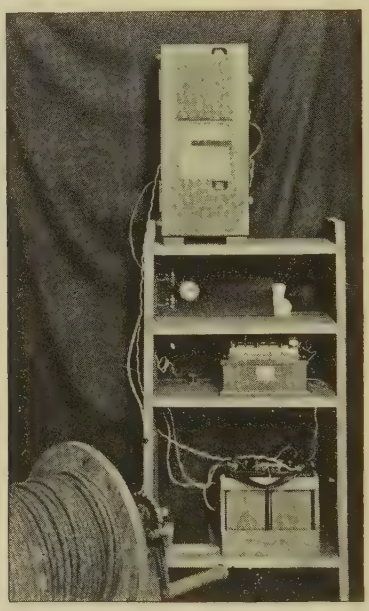

Fig. 3.

allow of 8 hours continual registration, marks the time for 20 revolutions of the propeller and the respective directions.

The apparatus, as shown in these figures, is of a new and improved construction, manufactured by Siemens & Halske A. G., Berlin, to whom I am much indebted for the excellent workmanship. The same firm made the registering ammeter. The experience gained in previous years has been duly taken into consideration; the exterior is streamlined, the friction is reduced to a very small quantity, and the pressure compensating-mechanism is placed in the watertight box. The supporting cable is an old one, bought from Felten & Guillaume, Lahmeyer-Werke, in 1912, and is still in good condition.

3. Carrying out the Observations is very simple. An accumulator, a rheostat for balancing the resistance in the branch corresponding to the direction 360° up to $33^1/_3$ ohm, and a shunt with the same resistance for

controlling the voltage of the accumulator, which can also be roughly controlled with a voltmeter, all shown in fig. 3, are all the necessary instruments for which shelter has to be arranged in a convenient part of the ship. The clockwork of the ammeter has to be wound up, the electric current to be turned on and the current-meter to be lowered to the successive depths desired. The bearing of the anchored ship is to be noted, for correcting the directions for deviation.

In the surface layers the current in the neighbourhood of the ship is affected by damming up against the ship. It is therefore better to determine this current by the aid of floating buoys.

4. The Constants of the Current-Meter to be used for deducting the velocity are to be determined empirically. Generally tables giving the velocity directly from the time are used. In work at sea, as the movements of the ship and also pulsations of the current disturb the data, another way is preferable. Let, for example, two consecutive intervals between contacts be 60 and 180 seconds, corresponding to 21.3 and 7.4 cm/sec. We have to remember, when taking the mean, supposing the direction to be the same, that the weight of the number 7.4 is three times as great as that of 21.3. We thus get 10.9 cm/sec, while the direct mean would give too great a value, 14.4 cm/sec. It is thus more convenient, especially as the direction commonly changes also, to deal with the travel of the current. In the example above, 60 and 180 seconds correspond to a distance of 12.8 and 13.4 metres; 26.2 metres in 240 seconds give us a velocity of 10.9 cm/sec.

One can derive a formula for reducing the indications of the current-meter by considering, for instance, the loss of momentum.

Let l be the travel of the current in the time t between two contacts. The velocity l/t of the water-particles is diminished by the hydrodynamic resistance of the propeller, the friction and work done in the apparatus, and may be written as r/t on leaving the screw. This velocity is again proportional to the velocity of rotation n/t, or $r=kn$.

The hydrodynamic resistance may be written as $al^2/t^2 + bl/t + c$, the resistance in the apparatus by friction and work done as $d + en/t$ or $d + fr/t$, the first term in both cases being of greater importance.

The loss of momentum per second balances the resistance. Hence

$$l/t\,(l/t - r/t) \backsim al^2/t^2 + bl/t + fr/t + c + d.$$

With other constants

$$l^2/t^2 = Alr/t^2 + Bl/t + Cr/t + D,$$

or

$$l^2 = Alr + (Bl + Cr)\, t + Dt^2.$$

This can be abridged in different ways. A satisfactory approximation is obtained from

$$l^2 = \alpha + \beta t + \gamma t^2.$$

The constants of the relation have been determined for the current-meter in question in a concrete basin 100 metres in length, over which the current-meter has been conveyed at different speeds on a waggon on rails. This gauging has given, l in metres, t in seconds,

$$l^2 = 160.25 + 0.0641\, t + 0.000205\, t^2.$$

From this the values of l as a function of t may be tabulated for convenience.

The travel of a very strong current necessary for 20 revolutions, or the interval between two contacts, is consequently 12.66 metres. The velocity for $t = \infty$ is 1.43 cm/sec. As the work in the apparatus is not quite evenly distributed between two contacts, the velocity of the current at which the apparatus begins to work is in reality somewhat higher, but clearly less than 2 cm/sec. A special investigation gives the value 1.6 cm/sec for that part of the interval between the contacts in which the principal part of the raising of the needle takes place, and 1.0 cm/sec for the remaining part.

5. The Deviation of the magnetic needle of the current-meter, caused by the iron mass of the ship, attains an appreciable influence when working with the meter in relatively small depths. As the total deviation consists of the so-called permanent, sub-permanent and induced deviations, changes in its amount may occur (4).

In transparent sea-water the determination of the deviation can be carried out, for example, as follows. Using a rule on the gunwale of the ship marked in half metres, on which decimetres can easily be read, the angle between the axis of the ship and of the current-meter is determined by aiming from the rule at the moment when the direction is registered. The results of these determinations show that even during such a short time as the 8 days in the Kattegat the deviation underwent changes. At the beginning before the evening of the 12th August the ship was lying almost in the same direction as the current-meter, about NW, and the deviation for the current-meter at 5 metres depth was, ship at 340°, about 39° ± 4°. From this time up to the morning of the 14th, the ship was heading almost NE, and thereafter between N and W for about a day, and the deviation, ship at 340°, decreased to — 24° ± 3° at noon on the 14th, and to — 1° ± 3°

at noon on the 15th. Later on, when the ship was veering almost round the compass, no change in the deviation was noticeable. The deviation at 5 metres depth during this later part of the work can be given, s being the direction of the ship, as

$$\delta_5 = +20^\circ + 26^\circ \cos(s - 199^\circ) + 8^\circ \cos(2s - 58^\circ)$$

which formula with a mean error of $\pm 3^\circ$ follows a curve drawn through the different determinations. Taken as a whole, the directions of the current at 5 metres depth, determined directly, and those registered and corrected for deviation differ by $\pm 3^\circ$.

For calculating the deviation in greater depths the following considerations are used. The deviating force is $k/r^2 \cos v$, r being the distance between the needle of the current-meter and the magnetic pole of the ship, and v the angle of r from the horizontal plane. $\cos v = a/r$, a being the distance of the supporting cable from the magnetic pole of the ship. As $h \sin \delta$ is the reaction of the needle,

$$h \sin \delta = ka/r^3.$$

And at the depths m and n

$$\sin \delta_m / \sin \delta_n = r_n^3 / r_m^3$$

where, d being the depth of the needle below the magnetic pole of the ship,

$$r^2 = a^2 + d^2.$$

A determination of the deviation at 3 metres depth on the 22nd August gave an amplitude for δ_3 of 57°.5. For δ_5 the amplitude of 27°.5 was found. The ratio of their sines is 1.85. The cable hung 2 metres away from the ship's side. Assuming the magnetic pole to lie at sea-level, athwart the current-meter in the central axis of the ship, whose breadth is 6.1 metres, we get

$$\sin \delta_3 / \sin \delta_5 = 1.78$$

which corresponds fairly well with the number above.

Thus, using the formula above, the deviations for different depths would be about as

$$\delta_5 : \delta_{10} : \delta_{15} : \delta_{20} : \delta_{25} : = 1 : 1{,}1 : 1{,}11 : 1{,}25 : 1{,}47.$$

Values calculated in this way are used for correction of the directions registered. For the greater depths the corrections are small.

6. The Reduction of the Observations. The current-meter gives us the following information (fig. 4 shows the registrations): the direction A at a moment K when the circuit is closed, the time $KK = t$ elapsed between this moment and the moment K of the following contact and the corresponding direction A. Here the time KK is divided into two parts, KF from the beginning of the contact to its end, and FK from the end to the beginning of the next contact. These parts, as well as the interval FF, can also be used for determining the velocity, when needed.

In general only the times KK are taken into account. Using a table

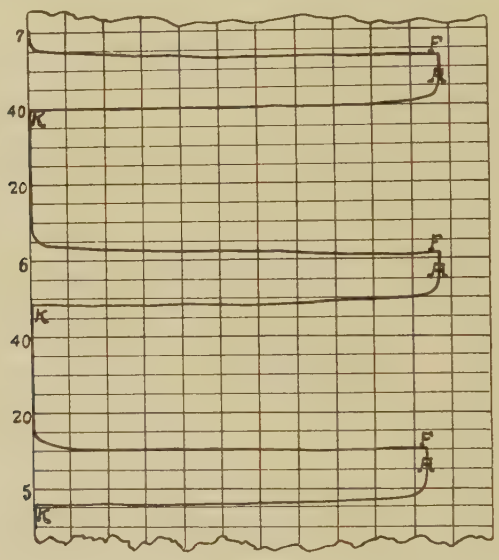

Fig. 4.

for converting the time KK to l, the column of water which has gone through the meter in the time KK, we thus have a series of statements A_1; l_1; t_1; A_2; l_2; t_2; A_3 . . . .

As the movements of the ship or pulsations in the current influence these results, the succesive values of A may differ, and the length l may not be a straight line. The simplest supposition is to take as corresponding data the mean M of the two consecutive values of direction, and, assuming that the direction changes continuously between the two contacts, as displacement, w, the length of the chord corresponding to the arc whose tangents are A_1 and A_2, or writing the difference between the A's as Δ, $w = l \cdot 2/\Delta \cdot \sin \Delta/2$, the values of w tabulated with l and Δ as arguments.

The travel of a water-particle in relation to the current-meter can thus be given as a broken line, made up as consecutive w's, see fig. 5,

giving this travel on August 13th from $18^h\ 8^m$. to $18^h\ 29^m$ in the depth of 25 metres. Here we get a total displacement of 186 metres in 1141 seconds or a velocity of 16.3 cm/sec from 322°, or 314° true. In this way about two-fifths of the material have been reduced. The criterion used for the employment of the graphical method has been that two of the A-values in a series should differ 30° or more from each other. In the other, better, cases means of M have been formed and, when summing the w's up, a small correction for reducing them to their projection on the mean direction has been applied.

This method is to obtain the final values. When working at sea rough values of velocity and direction can be read directly from the registrations, thus making it possible to follow immediately the distribution of the currents and any changes that may occur.

7. A Measure of the Accuracy of the observations could be deduced from the discrepancies of the different data of a series at one particular depth. When many series are made, in our case more than a thousand, this method involves long calculations. The following deliberation allows instead a judgment to be formed of the limits within which the velocity found can be regarded as sure. At a certain depth a series of n consecutive observations has been made. Assuming that the $(n+1)^{th}$ observation, if taken, had given a value of velocity as great as the greatest found for one interval of contacts, and of the main direction, the resulting current deduced from these $n+1$ observations would most likely be too great. In taking for this assumed $(n+1)^{th}$ current-observation the observation giving the weakest current or the longest contact-interval, the resulting current would be too small. The difference between these values delimits an interval in which the true velocity will most probably fall. The two directions M deviating the most to the right and to the left from the mean direction of the series, could also, taken as a supplementary observation, indicate the limits within which the resulting direction may be assumed most probably to fall.

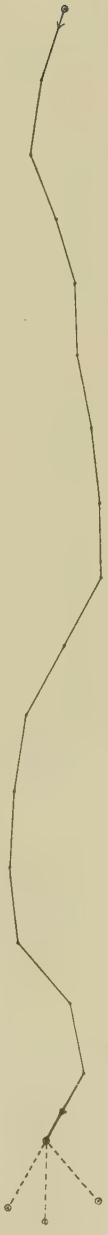

Fig. 5.

In the example, fig. 5, the thick lines are the actual observations of the series, the broken lines indicate the assumed $(n+1)^{th}$ observations. The velocity is here 186 m. in 1141 seconds, or 16.3 cm/sec; the greatest

value of *KK*, the interval between two contacts, is 120 seconds, and the shortest interval is 37 seconds. Adding 13 metres, corresponding to one interval between contacts, we obtain 199 metres of water flowing in, respectively, 1261 and 1178 seconds or 15.8 and 16.9 cm/sec. In this instance we can conclude that the difference between the limiting values is about 1 cm/sec or that the error may be less than 0.5 cm/sec. The resulting direction is 314° true. In the same way a $(n + 1)^{th}$ observation of 272° or 342° true would give resulting directions of 311° or 316°, indicating an error less than 3°. As the error in velocity almost corresponds to the error in the direction, although the error in the direction is relatively greater for small velocities, and as many series are too short to allow of as exact a determination of the errors as above, with a view to shortening the work we have calculated the values of these limits only for the velocities, or, a series in a depth being too short, estimated these values with due regard to the nearest series.

Thus, when half the difference between these limiting values has been about $^1/_4$ cm/sec or less, we have put the letter *a* after the velocity. The letter *b* corresponds to a limiting interval of 1 cm/sec or limiting errors less than $^1/_2$ cm/sec, the letter *c* to a limiting error of 1 cm/sec, and *d* to greater estimated intervals. The example above would then give 315°, 16 cm/sec, *b*, rounding off the directions to multiples of 5 degrees and the velocities to whole cm/sec. The short time available for a series and the sometimes appreciable fluctuations of the current make tenths of cm/sec illusory for a great part of the material.

In comparatively good weather an accuracy of 0.1 cm/sec is nevertheless easily attained, when a space of time up to ten minutes can be spared for a series of measurements at one depth. In rough weather it is possible to arrive at similar accuracy by lengthening the time of observation. By using several current-meters, so that enough time can be given to the measurements at each depth, in this way very good values may be obtained. The reduction is comparatively simple. For studying the pulsations of the current simultaneous series of observations are, of course, to be made. Such series in three depths may suffice to separate both the pulsations and the displacements of the ship.

8. Some Results of the work in the Kattegat may be mentioned to show the amount of data which can be obtained with one instrument in use. In one hour, series of measurements at the depths 5, 10, 15, 20, 25 metres and near the bottom were made, occasionally also a measurement at some intermediate depth. As the surface current was also determined with a floating buoy, we have consecutive values for each depth at intervals of about one hour. The material is laid out in an isoplethic

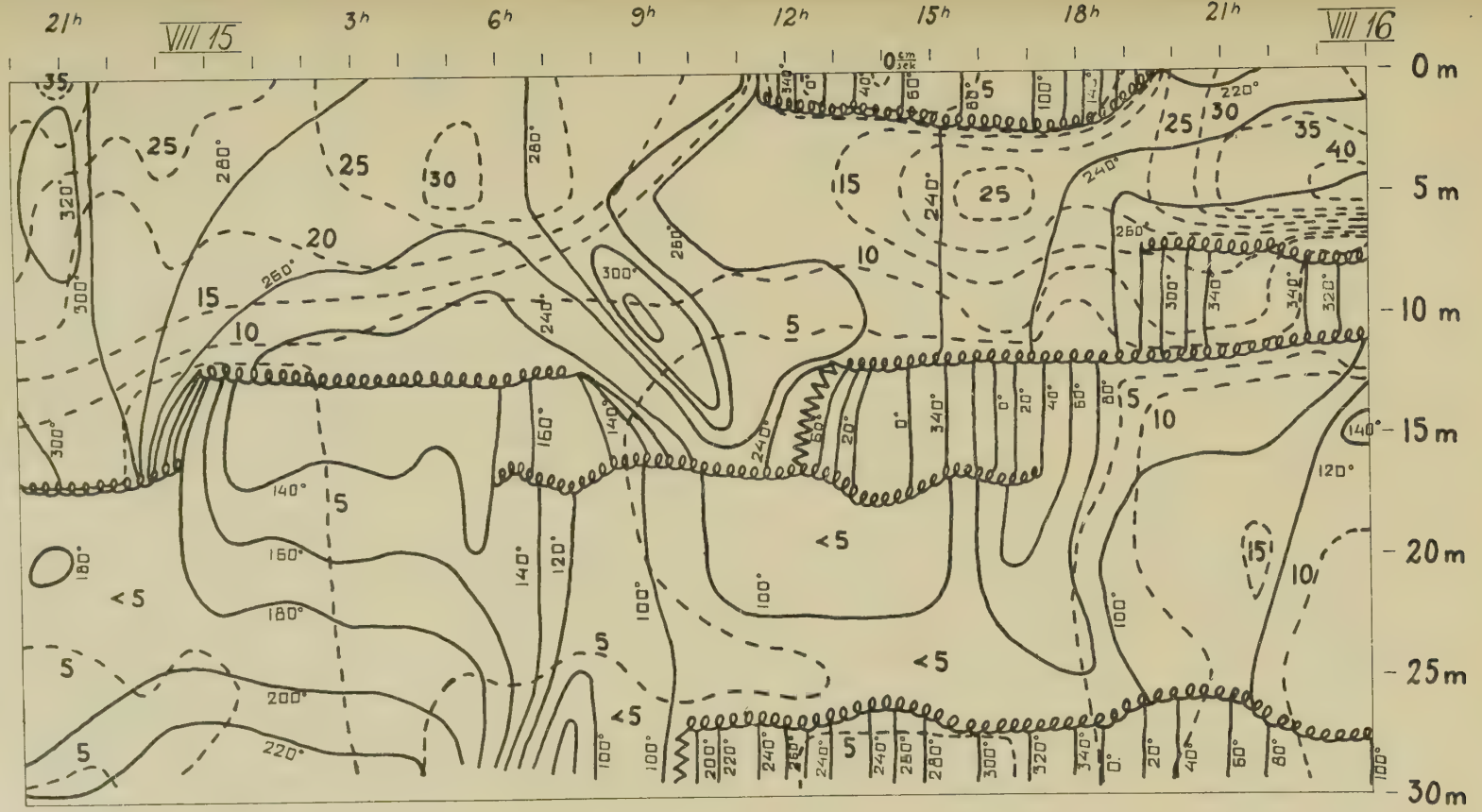
21h
VIII 15
3h
6h
9h
12h
15h
18h
21h
VIII 16
0 m
5 m
10 m
15 m
20 m
25 m
30 m

Fig. 6.

diagram of which the figures 6 and 7, p. 227 and 229, give two abstracts for the days August 15th and 16th. The depths are taken as ordinates, the time as abscissae. The thick lines give the direction of the current, 0° designating a current from the north, 90° from the east, and so on. These isogones are drawn for every 20th degree. The broken lines give the velocities. These isotaches are shown for every 5th cm/sec. The numbers are written on the side towards increasing values.

A glance at the isopleths shows that the currents are rather complicated. In many instances an exact representation would require observations much closer together than ours, which were mostly taken at every 5th metre. Almost every observation at an intermediate depth has given information of value. Surely observations a little closer in depth and a little more sparse in time would have given a more lucid explanation of the course of the currents, for example, every 90th minute at every 3rd metre. Some arbitrariness in drawing the lines could thus not be avoided, but these lines may nevertheless interpret the general character of the distribution of the currents, although it may be regarded as possible that some characteristic feature has occasionally escaped through our net of data.

On many occasions we find that in velocity, and more often in direction, the current changes very rapidly with the depth. Many thin strata of kinematic transition are found to occur. Sometimes the manner in which the direction screws with the depth can be traced and the isogones drawn more or less satisfactorily, but often in such cases the stratum is very thin and the interpretation by isogones difficult; sometimes again almost a gliding seems to be present, evidently corresponding to a thin stratum of eddies. A schematic indication of the strata of kinematic transition by "eddying" lines is used as giving a better synopsis than crowded hypothetic isogones. Sometimes the current seems to turn over to an almost contrary direction. These occasions are indicated by a broken line.

The situation of the strata of kinematic transition is of great interest. Let us consider fig. 6, p. 227, giving the current for the 15th August. In this instance these strata almost correspond to the isohalines 15, 18, 21, 31, and 32.5 $^0/_{00}$, as shown in fig. 8, which gives the temperature, salinity and density at 17^h, and where also the strata of kinematic transition are marked by eddying lines. Five strata thus separate six different layers of water. The surface layer existing from about 10^h to about 20^h is a layer of comparatively low salinity, which appears and disappears. This layer shows during the whole time of its appearance a current evenly turning to the right, quite independent of the current of the underlying

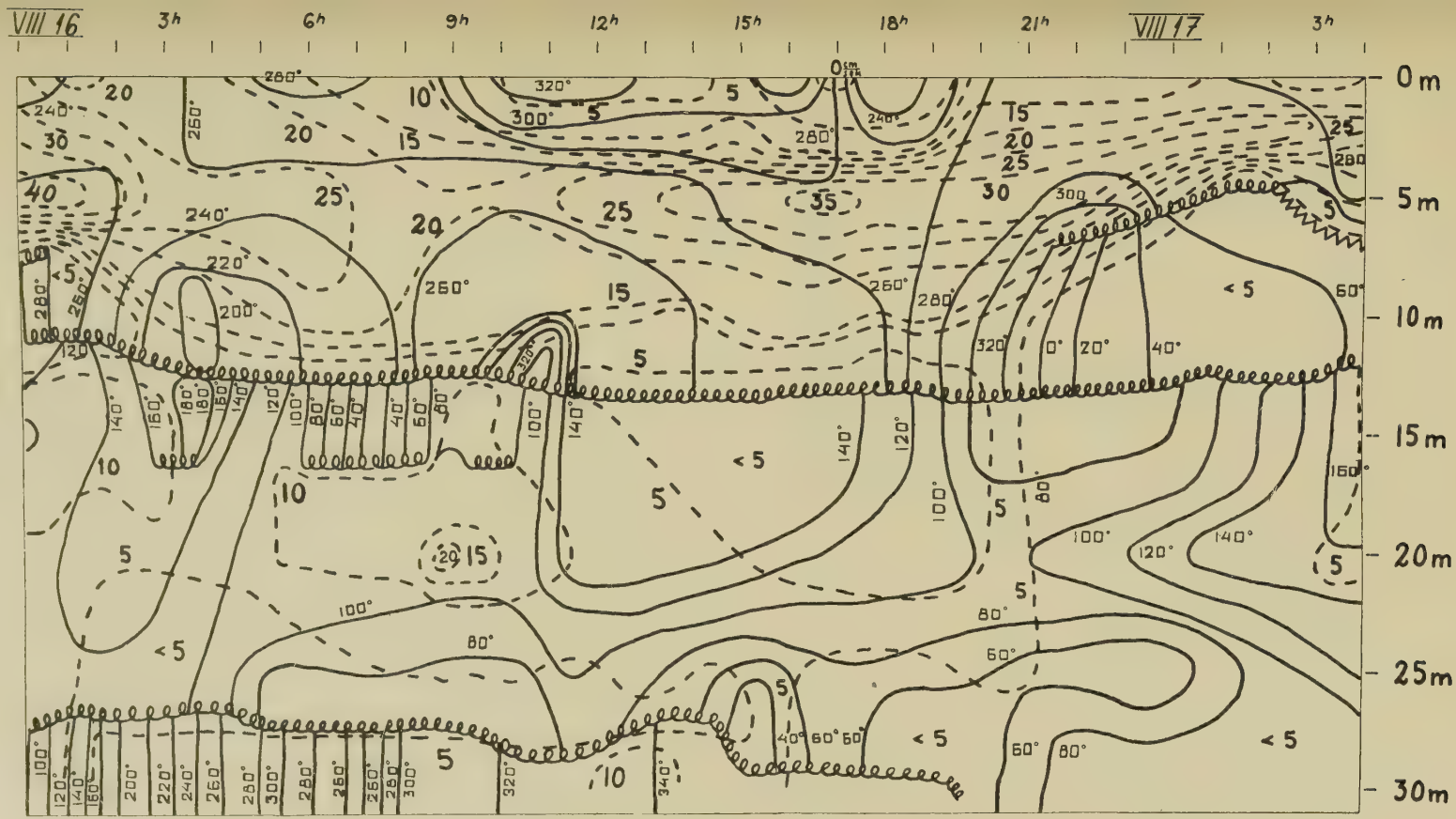
VIII 16
3h
6h
9h
12h
15h
18h
21h
VIII 17
3h
0 m
5 m
10 m
15 m
20 m
25 m
30 m

Fig. 7.

layer. Of the other layers, two or more for a time move almost as one entity, but suddenly one or the other differs from its neighbour and shows independent changes of the current; after a time the layer again kinematically merges with an adjoining one, at least to all appearance. Thus, for instance, the layer with a salinity from about 21 to about 31 $^0/_{00}$ at the beginning and at the end of the day moves in almost the same way as the underlying layer, but differs from the latter between about 6^h and 17^h, a stratum of transition at about 16 metres depth. At other depths such strata of transition come about and vanish at different times, as

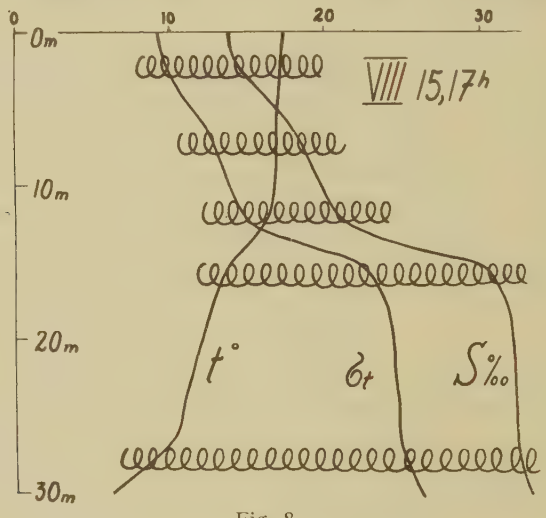

Fig. 8.

shown in the figures 6 and 7. Further, when several layers are moving nearly as an homogeneous mass, one intermediate layer can develop a peculiar system of currents, giving the impression almost of an injection of water (August 13th, 9^h to 18^h at 15 metres).

Generally, these strata of kinematic transition do not seem to be situated in the depths where the increase of density shows maxima, but rather in or near the depths where the rate of this increase changes, corresponding, in a graph such as fig. 8, to the depths where the lines of variation of t°, S $^0/_{00}$ and thus of σ_t with the depth show a greater curvature. Thus a layer of haline transition, such as ours from 21 to 31 $^0/_{00}$, does not inevitably indicate the existence of kinematic transition at its middle, in this instance at about 14 metres. The kinematic transition can be met with in its upper and its lower stratum, here at about 12 and 16 metres. But while this layer of haline transition may kinematically join the adjoining upper or lower layer alternately, on considering where

the mean conditions are thought to lie the layer of haline transition may of course be regarded as containing a fictitious stratum of kinematic transition. But on the other side as the depth and thickness of the characteristic layers may subsequently change, the data for a particular depth are not always to be considered as equivalent, especially in studying the resulting and the periodical phenomena.

The kinematic conditions are thus more complicated than previously assumed. The appearance of strata of kinematic transition, at or near the depths of greater curvature of the rate of increase of density with the depth, make it probable that in other regions also, where the width of the variations in density is smaller, similar stratification and possibly also "gliding" may occur. The conception of the sea as constituted of different units, i. e., layers separated by discontinuities in several respects and behaving each in its own way, gains support.

On several occasions the current at some depths for a short time varied very irregularly, mostly in velocity, when at other depths no great change was to be observed. We had, for example, on the 15th August, in a series of observations of about ten minutes duration, in greater depths small velocities, at about 5^h00^m (time of the middle of the series) at a depth of 28 metres 3 cm/sec, at 6^h14^m and 7^h16^m at 29 metres 2cm/sec, but between these series we had at 5 metres at 6^h00^m velocities varying from 19 to 44 cm/sec and at 7^h03^m from 22 to 42 cm/sec; and again, as another example, on the 16th, in a series of about five minutes duration, at 25 metres depth at 7^h41^m and 8^h38^m velocities of 6 and 5 cm/sec, but between these at 7^h56^m at 20 metres velocities varying from 11 to 41 cm/sec. The displacement of the ship can hardly explain these variations. We must clearly have met with the great variations in the depths of the small velocities also, had the displacements of the ship been the cause. The conclusion, that the current was pulsating, almost from minute to minute, seems justified. But, I think, we may regard the data which our material can provide just as hints. The real nature of the pulsations can only be revealed by special studies where, as mentioned, simultaneous observations at several depths are used. We have to remember the complications and the sources of error. Where the current rapidly changes with the depth, occasional vertical undulations of short duration of the kinematic strata may produce notable alterations of the current at a particular depth, although the current in the different strata may be almost unaltered. Variations of the depth at which the current-meter works, caused by the rolling of the ship, can also disturb the indications. And further the displacements of the ship are commonly greater than in the instances given above.

9. Summary. The paper describes a current-meter, its construction and the methods for the reduction of the observations, and gives the results of some measurements made in the Kattegat last summer. These results (see figs. 6, and 7, p. 227 and 229) indicate that the currents can be rather complicated. Strata of rapid kinematic transition — where eddying and almost gliding occur — divided the sea into several layers within which pulsations of the current were to be assumed.

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Über den Einfluss des Wasserdruckes auf *pH* und das Kohlensäuregleichgewicht in grösseren Meerestiefen.

Von

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Die Wasserstoffzahl des Meerwassers (*pH*) wird, nach den Ergebnissen der neueren Untersuchungen über das Kohlensäuregleichgewicht im Meerwasser, fast ausschliesslich von der Kohlensäure und den Karbonaten des Wassers bestimmt. Die bisherigen Forschungen auf diesem Gebiet haben sich ausschliesslich auf das Studium des Gleichgewichtszustandes an der Oberfläche bezogen.

Der mögliche Einfluss von hohen Drucken, wie sie in den grösseren Meerestiefen vorhanden sind, ist nicht diskutiert worden, hauptsächlich wohl, weil keinerlei Anhaltspunkte zur Beurteilung dieses Faktors vorlagen. Nach den theoretischen und experimentellen Untersuchungen hauptsächlich von Tammann und seinen Mitarbeitern ist indessen bekannt, dass z. B. die Leitfähigkeit der Elektrolyte durch starke Erhöhung des Druckes stets mehr oder weniger verändert wird. Die Grösse der Beeinflussung ist von der Art des Elektrolyten abhängig. Die drei Haupttypen, starke, mittelstarke und schwache Elektrolyte, unterscheiden sich in dieser Hinsicht in markanter Weise von einander, sodass das Verhalten gegen Drucke gut zu ihrer Charakterisierung beiträgt.

Die schwachen Säuren verhalten sich, wie die experimentelle Erfahrung lehrt, in ziemlich gleichartiger Weise. — Die Leitfähigkeitsmessungen ermöglichen in bekannter Weise die Feststellung des Dissoziationsgrades der Säure. Aus der letzteren lässt sich die Dissoziationskonstante berechnen. Nach experimentellen Untersuchungen von E. Brander ändern sich die Dissoziationskonstanten verschiedener Säuren, besonders derjenigen, die einander in Bezug auf Atom-Anzahl und -Bau ähnlich sind, mit ungefähr gleichen Beträgen, sodass die Druckfaktoren

einer Säure annähernd auch die Druckfaktoren anderer Säuren vertreten können. Als Beispiel mögen Branders Druckkoeffizienten für Essigsäure und Fumarsäure (erste Diss. Stufe) für den Druck von 1000 kg pro cm² angeführt werden, welcher Druck ungefähr den höchsten im Meere vorhandenen (in der Tiefe von etwa 10000 Metern) repräsentiert. Brander berechnet nämlich aus Leitfähigkeitsmessungen von Tammann den Druckkoeffizienten $K(p)/K(1)$, welcher die Zahl bezeichnet, mit welcher die Dissoziationskonstante der Säure bei Atmosphärendruck multipliziert werden muss, um die Konstante beim Drucke p(kg/cm²) wiederzugeben, für Essigsäure zu 1.53 und für Fumarsäure zu 1.47.

Tabelle 1.

(p) kg/cm²	$K(p)/K(1)$ Kohlensäure, erste Diss.-Stufe		$K(p)/K(1)$ Essigsäure. Verdünnung 10/L Mol
	Verdünnung I 24.45 L/Mol	Verdünnung II 58.43 L/Mol	
1	1.000	1.000	1.000
500	1.738	1.733	1.240
1000	2.940	2.935	1.530
1500	4.822	4.817	1.847
2000	7.724	7.710	2.186
2500	12.18	12.19	2.567
3000	18.76	18.68	2.898

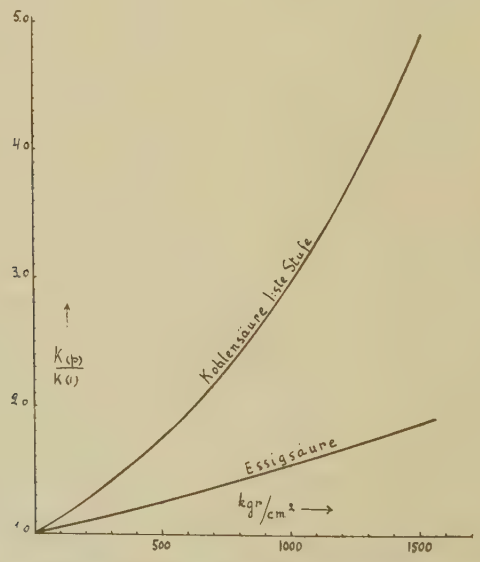

Fig. 1. Graphische Darstellung des Verlaufs des Druckkoeffizienten für beide Säuren.

Das Verhalten der Kohlensäure weicht indessen in dieser Hinsicht von den übrigen Säuren in beträchtlichem Masse ab, indem die erste Dissoziationskonstante (die scheinbare Konstante, wo sowohl die unhydratisierten Moleküle CO_2 wie die hydratisierten H_2CO_3 mit einbezogen sind) mit dem Drucke bedeutend mehr zunimmt als die Konstanten der anderen Säuren —, wie die in voranstehender Tabelle 1 zusammengestellten Zahlen von Brander ergeben, denen zum Vergleich auch die Werte für Essigsäure beigefügt sind. Brander's Messungen an Kohlensäure wurden in zwei verschiedenen Verdünnungen ausgeführt, welche ergeben, dass die Druckkoeffizienten von der Verdünnung unabhängig sind.

Brander hat auch die Ursache für das abnorme Verhalten der Kohlensäure nachgewiesen. Es ist darauf zurückzuführen, dass bei der Ionenbildung

$$CO_2 + H_2O \overset{\nearrow H_2CO_3 \searrow}{\longrightarrow} HCO_3' + H^{\cdot}$$

ein Molekül Wasser verschwindet, wodurch das Volumen der Lösung vermindert wird. Erhöhter Druck muss also den Ionenbildungsvorgang begünstigen.

Die Werte der Tabelle 1 bilden die Unterlage für die folgenden Berechnungen des Druckeinflusses auf das Gleichgewichtssystem der Kohlensäure in den grösseren Meerestiefen. Hierfür ist in Meerwasser massgebend sowohl die erste wie die zweite Konstante der Kohlensäure. Brander's Messungen, vorgenommen an Lösungen von Kohlendioxyd in Wasser, beziehen sich naturgemäss nur auf die erste Konstante. Die zweite kommt in dem sauren Milieu, bei welchem die Messungen stattfanden, nicht in Betracht. Im alkalischen Milieu des Meerwassers ist sie jedoch zu beachten. Da der Einfluss, den der Druck auf sie ausübt, indessen nicht bekannt ist, sind wir gezwungen, die Werte einer anderen ähnlichen u. zw. einer einbasischen Säure zu benutzen, indem wir das HCO_3'-Ion, welches normal dissoziiert, als einbasische Säure betrachten. Von den bisher in Bezug auf den Druck untersuchten Säuren kommt die Essigsäure ihrer Konstitution nach am nächsten in Betracht. Über die Grösse der hierdurch entstehenden Unsicherheit gibt die oben erwähnte Differenz der Druckkoeffizienten der Essigsäure und Fumarsäure (für den selten vorkommenden Maximaldruck 1000 kg/cm$_2$) Auskunft. Logarithmiert beträgt sie nur 0.01 Einheiten des Logarithmus der Dissoziationskonstante. Da HCO_3' der Essigsäure ähnlicher ist, können wir hier nur eine kleinere Differenz erwarten, die wir vernachlässigen können. Da uns in erster Linie die Gleichgewichtslage des CO_2-Systemes in bestimmten Meerestiefen interessiert, haben wir unter

Anwendung der »Tabellen für Meerwasser unter Druck« von V. Walfrid Ekman die obige Tabelle von Brander auf die Meerestiefen in Metern (bei $Cl = 19.5\,‰$ und einer mittleren Temperatur der Wassersäule von $t = 5°$) umgerechnet, wo die von Brander angegebenen Drucke herrschen, und dann für zwischenliegende Tiefen interpoliert. Die Druckkoeffizienten geben wir in Form ihrer Logarithmen ΔpK an. Die Tabelle 2 enthält die so erhaltenen Werte von ΔpK_1 (erste Konstante) bzw. ΔpK_2 (zweite Konstante), welche von den für Atmosphärendruck gültigen pK-Werten abzuziehen sind, um für die nebenbei angegebenen Tiefen zu gelten.

Die in der Tabelle 2 angegebenen Werte können wir nun zur Berechnung der Verschiebung des CO_2-Gleichgewichtes mit zunehmender Tiefe verwerten. Diese Berechnung gründet sich wie diejenige des Gleichgewichts im Oberflächenwasser auf die beiden Massenwirkungsgleichungen für die erste und zweite Dissoziationsstufe der Kohlensäure, wobei wir die für die Oberfläche gültigen Werte der Konstanten mit denjenigen für die betreffende Tiefe ersetzen. Die Berechnungsweise für die Oberfläche ist früher von Buch (3) entwickelt.

Tabelle 2.

Einfluss des Wasserdruckes in verschiedenen Tiefen auf pK_1 und pK_2.

ΔpK_1	Tiefe in M.	ΔpK_1	Tiefe in M.	ΔpK_2	Tiefe in M.
— 0.02	400	— 0.26	5300	— 0.02	1100
.04	800	.28	5700	.04	2100
.06	1200	.30	6100	.06	3200
.08	1600	.32	6500	.08	4200
.10	2000	.34	6900	.10	5300
.12	2400	.36	7300	.12	6300
.14	2800	.38	7800	.14	7400
.16	3200	.40	8200	.16	8400
.18	3700	.42	8600	.18	9500
.20	4100	.44	9100		
.22	4500	.46	9500		
.24	4900	.48	10000		

Die Gleichungen lauten:

1) $$\frac{a_{H^\cdot} \cdot c_{HCO_3'}}{c_{CO_2}} = K_{c_1}\,^{1})$$

2) $$\frac{a_{H^\cdot} \cdot c_{CO_3''}}{c_{HCO_3'}} = K_2'.$$

[1]) Die durch Gl. 1) definierte Konstante wird K_{c_1} statt K_1' genannt, um die

a_H bedeutet die Wasserstoffionenaktivität, deren negativer Logarithmus konventionell durch die von S. P. L. Sörensen definierte Grösse pH wiedergegeben ist. $c_{HCO_3'}$, $c_{CO_3''}$ und c_{CO_2} sind die Konzentrationen, in Molen CO_2 pro Liter, der durch das Index bezeichneten Molekül- bzw. Ionenarten. (c_{CO_2} = Summe der hydratisierten, H_2CO_3-, und unhydratisierten CO_2-Moleküle).

Die Dissoziationskonstanten K_{c_1} und K_2' variieren mit der Temperatur, dem Salzgehalte und dem Drucke.

Der Einfluss der beiden ersten Faktoren ist ausführlich in einer demnächst erscheinenden Arbeit von Buch, Harvey, Wattenberg und Gripenberg (1) behandelt und in Tabellen für Atmosphärendruck wiedergegeben. Um für die Tiefe gültige Konstanten zu erhalten, haben wir an den Oberflächenwerten, oder richtiger an deren negativen Logarithmen pK_{c_1} bzw. pK_2' die Korrekturen ΔpK der Tabelle 2 anzubringen. Da die Gleichungen vier Unbekannte enthalten, benötigen wir noch folgender zwei, von Buch[1]) benutzten Gleichungen, welche die Beziehung zwischen den Kohlensäurekonstituenten und den analytisch ermittelbaren Grössen, Titrationsalkalinität und Totalkohlensäure darstellen:

Bezeichnungsweise in einer demnächst erscheinenden Arbeit »Über das Kohlensäuresystem im Meerwasser« von Buch, Harvey, Wattenberg und Gripenberg zu benutzen. Die Bezeichnung K_1' wird in dieser Arbeit für die durch die Gleichung

$$\frac{a_H \cdot c_{HCO_3'}}{a_{CO_2} \cdot a_{H_2O}} = K_1'$$

gegebene Konstante angewandt. Für a_{CO_2} (Aktivität der freien Kohlensäure) und a_{H_2O} (Aktivität des Wassers) gelten aber

$$a_{CO_2} = c_{CO_2} \cdot \frac{c_0}{c_S}$$

$$a_{H_2O} = \frac{p}{p_0}$$

wo c_0 und c_S die Löslichkeiten der Kohlensäure in reinem Wasser und in Wasser vom Salzgehalt S, p_0 und p die Dampfdrucke des reinen Wassers und Wassers vom Salzgehalt S bedeuten. Die oben definierte Konstante K_{c_1} ist somit mit der Konstante K_1' durch die Beziehung

$$K_{c_1} = K_1' \cdot \frac{c_0}{c_S} \cdot \frac{p}{p_0}$$

verbunden. Tabellen die K_1', K_{c_1}, c_0 und c_S sowie $\frac{p}{p_0}$ enthalten, sind in der erwähnten Arbeit gegeben.

[1]) Dissertation Seite 77. Kohlensäurefaktoren Seite 57.

3) $$\text{Titr.-Alkalinität} = c_{HCO_3'} + 2c_{CO_3''}$$

4) $$\text{Totalkohlensäure } (c_{\Sigma CO_2}) = c_{CO_2} + c_{HCO_3'} + c_{CO_3''}.$$

Die Gleichungen 1), 2), 3) ergeben

5) $$c_{HCO_3'} = \frac{\text{Titr.-Alk.}}{1 + \frac{2K_2'}{a_{H\cdot}}}$$

6) $$c_{CO_3''} = \frac{\text{Titr.-Alk.}}{1 + \frac{2K_2'}{a_{H\cdot}}} \cdot \frac{K_2'}{a_{H\cdot}}$$

7) $$c_{CO_2} = \frac{\text{Titr.-Alk.}}{1 + \frac{2K_2'}{a_{H\cdot}}} \cdot \frac{a_{H\cdot}}{K_{c_1}}$$

Die für c_{CO_2}, $c_{HCO_3'}$ und $c_{CO_3''}$ erhaltenen Ausdrucke in Gl. 4) eingesetzt ergeben:

8) $$c_{\Sigma CO_2} = \frac{\text{Titr.-Alk.}}{1 + \frac{2K_2'}{a_{H\cdot}}} \left(1 + \frac{K_2'}{a_{H\cdot}} + \frac{a_{H\cdot}}{K_{c_1}}\right).$$

Wir sind indessen noch keineswegs berechtigt, die Gleichungen 5), 6), 7) und 8) nach Einführung der Tiefenkorrektur von K_{c_1} und K_2' direkt zur Berechnung der bwz. links angeführten Grössen anzuwenden, denn wir operieren hier mit Grössen, Titr.-Alk. und $a_{H\cdot}$ bzw. pH, die analytisch nur im Oberflächenzustand ermittelt werden können. Wir haben daher zuerst die Abhängigkeit des pH vom Drucke zu untersuchen. Quantitativ besagt die Vergrösserung von K_1 bzw. K_2 bei zunehmendem Drucke, dass das Wasser saurer wird. Die an einer aus der Tiefe geschöpften Wasserprobe ausgeführte pH-Bestimmung gibt einen alkalischeren Wert als das Wasser in der Tiefe besass. Der quantitative Zusammenhang ergibt sich z. B. aus der Gl. 8), wenn wir dieselbe in Bezug auf $a_{H\cdot}$ auflösen[1]). Am einfachsten geschieht dies indem wir die Titr.-Alk. auf die linke Seite überführen und

9) $$\frac{c_{\Sigma CO_2}}{\text{Titr.-Alk.}} = A$$

[1]) Vergl. auch Dissertation von Buch Gl. 10) Seite 77.

setzen. Gl. 8) in reduzierter Form lautet dann:

$$10) \qquad a_{H\cdot}^{2} - K_{c_1}(A-1)\,a_{H\cdot} - K_{c_1}K_2'(2A-1) = 0.$$

Die Anwendbarkeit dieser Gleichung auch für die Tiefe gründet sich auf die Tatsache, dass ΣCO_2 und Titr.-Alk. einer aus der Tiefe zur Oberfläche gebrachten Wasserprobe von der Gleichgewichtsverschiebung, die bei Aufhebung des Druckes eintritt, unberührt bleiben. Die einzige Veränderung an diesen Grössen ist diejenige, welche von der Volumenvergrösserung des Wassers bedingt ist. Das Verhältnis beider bleibt aber dabei naturgemäss unverändert.

Die Tiefenkorrektur ΔpH können wir daher einfach in folgender Weise berechnen. Wir lösen die Gleichung 8) bzw. 10) zweimal auf. Zuerst in Bezug auf die Grösse A ausgehend von einem gegebenen pH, und von den Oberflächenwerten der Konstanten K_{c_1} und K_2', und sodann in Bezug auf pH unter Anwendung des erhaltenen A-Wertes und der für die betrachtete Tiefe gültigen K_{c_1} und K_2'. ΔpH ist die Differenz des Oberflächen- und Tiefenwertes.

Der Wert von ΔpH ist von verschiedenen Faktoren abhängig, in erster Linie von pH selbst. Aus den Gleichungen 1) und 2) ersehen wir, dass ΔpH in saurerem Wasser grösser sein muss als in alkalischerem. Für den Fall z. B., dass $c_{HCO_3'} = c_{CO_2}$, d. h. $a_{H\cdot} = K_{c_1}$ ist, wird ΔpH numerisch praktisch denselben Wert wie ΔpK_1 haben. Dies trifft z. B. zu für ein Wasser von 20° und $Cl = 19.5\,‰$ für $pH = 6.02$. Falls wieder $c_{CO_3''} = c_{HCO_3'}$ (im selben Wasser von 20° und 19.5 ‰ bei $pH = pK_2' = 8.75$) ist ΔpH wiederum praktisch identisch mit ΔpK_2. Für zwischenliegende Werte geht ΔpH kontinuierlich aber nicht linear vom einen Wert zum anderen über.

Fig. 2 stellt den Verlauf von ΔpH bei einer Tiefe von 10,000 Meter mit pH Oberflächenwert dar, gültig für ein Wasser von 19.5 ‰ Cl-Gehalt und $t = 0° - 5°$.

Der Umkehrpunkt dieser Kurve liegt bei dem pH, wo $c_{\Sigma CO_2}$ = Titr.-Alk. d. h. $A = 1$, oder in den Gleichungen 1) bzw. 2) $c_{CO_2} = c_{CO_3''}$ ist. Die Multiplikation dieser Gleichungen oder auch die Auflösung von Gl. 10) gibt uns die bekannte Gleichung

$$a_H = \sqrt{K_{c_1} \cdot K_2'}$$

woraus folgt

$$\Delta pH = 0.5\,(\Delta pK_{c_1} + \Delta pK_2').$$

In 10,000 Meter Tiefe ist in diesem Falle $\Delta pH = 0.5\,(0.48 + 0.19) = 0.34$.

Indessen variieren die Werte von K_{c_1} und K_2' mit der Temperatur und der Chlorzahl, woraus folgt, dass das pH, bei welchem die Grösse A den Wert 1 annimmt, auch mit diesen Faktoren variieren muss. Der Kurvenverlauf bleibt dabei unverändert, die ganze Kurve wird aber seitlich verschoben.

Wir haben also noch zu untersuchen, mit welchen Beträgen die in den Meerestiefen vorkommenden Variationen von t und Cl auf ΔpH

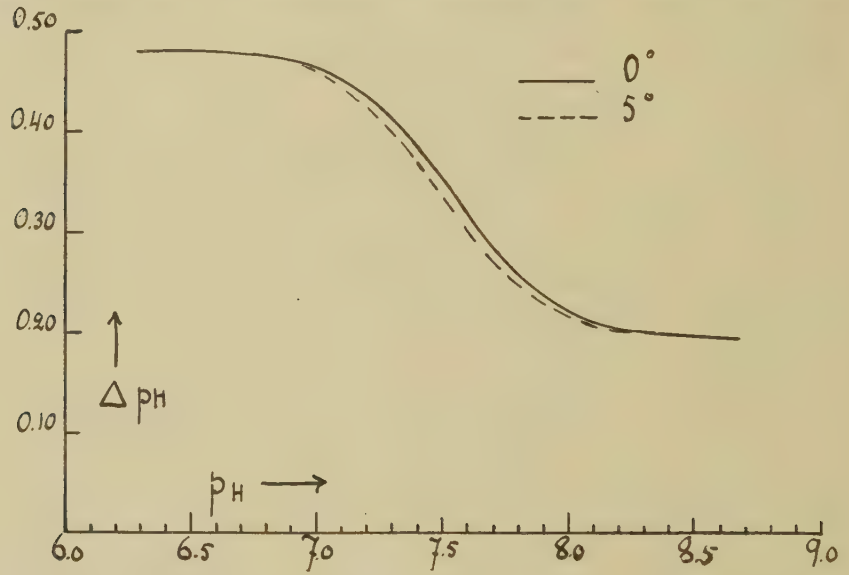

Fig. 2. Verlauf von Δp_H bei einer Tiefe von 10.000 Metern mit p_H an der Oberfläche, berechnet für ein Wasser von 19.5 ‰ Cl-Gehalt und $t = 0°$—$5°$.

einwirken. Wir können mit einer Variation der Temperatur zwischen 0° und 5°, sowie einer Cl-Variation zwischen 19 und 20 ‰ rechnen.

Eine Überschlagsrechnung ergab, dass sowohl der Temperatur- wie der Saltzgehaltseinfluss praktisch vernachlässigt werden kann. Die grösstmögliche Änderung von ΔpH von 0 bis 5°, nämlich in 10,000 Meter Tiefe und im sauersten Gebiet ($pH = 7.5$), beträgt 0.02 Einheiten, bei Anwendung einer mittleren Temperatur von 2°.5 also 0.01 Einheiten in jeder Richtung. Der Salzgehaltseinfluss ist noch geringer. Das Interpolationsdiagramm Fig. 3, zeigt, dass die Veränderung von pH linear mit der Tiefe verläuft. Die Doppellinien im saureren Gebiet gelten 0° und 5°. Die Salzgehaltsvariabilität ist graphisch nicht darstellbar. (Die Differenz in 10,000 Meter Tiefe bei $pH = 7.5$ zwischen $Cl = 19$ und 20 ist 0.01 Einheiten.)

Da die Kurven linear verlaufen, können wir das Resultat in folgender

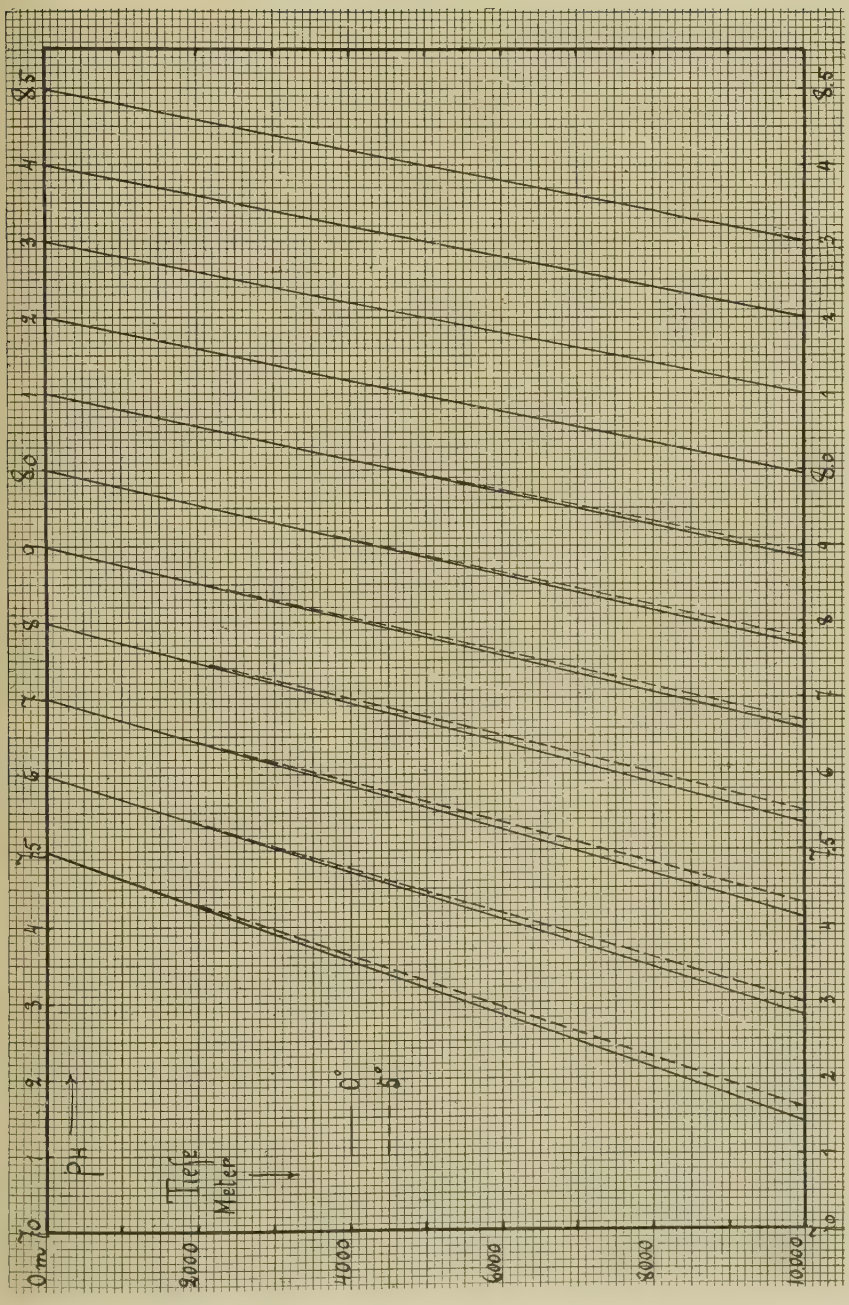

Fig. 3. Veränderung von p_H mit der Tiefe bei $t = 0°—5°$, berechnet für ein Wasser von 19.5 ‰ *Cl*-Gehalt.

Tabelle 3 darstellen, welche die ΔpH-Werte enthält, die pro 1000 Meter Tiefenzuwachs von den gemessenen (für den Oberflächenzustand gültigen) pH abzuziehen sind, oder

$$pH \text{ (Tiefe)} = pH \text{ (Oberfläche)} - \Delta pH \frac{\text{Tiefe}}{1000}.$$

Tabelle 3.

$Cl = 19.5\ ‰$ $\quad$ $t = 0° — 5°$

pH Oberfläche	7.5	7.6	7.7	7.8	7.9	8.0	8.1	8.2	8.3	8.4	
ΔpH (pro 1000 M)	0.035	0.031	0.028	0.025	0.023	0.022	0.021	0.020	0.020	0.020	0.

Nachdem uns die Feststellung von pH in der Tiefe möglich ist, können wir die Kohlensäurekonstituenten mit Hilfe der Gleichungen 5), 6) und 7) berechnen, in welche die Tiefenwerte von $a_{H^\cdot}$, K_{c_1}, K_2' und Titr.-Alk. eingesetzt sind.

Die Tiefenwerte der Titr.-Alk. und Totalkohlensäure sind, wie erwähnt, nur um den Betrag der Kompression des Wassers grösser als die für den Oberflächenzustand gültigen. Wir erhalten sie durch Multiplikation des Oberflächenwertes mit dem Verhältnis der spez. Gewichte s_m/s_o des Wassers in 0 und m Metern, dessen Werte in folgender kleinen Tabelle für verschiedene Tiefen angeführt sind.

Tabelle 4.

s_m/s_0	1.010	1.020	1.030	1.040
Tiefe in Metern	2200	4700	7300	9800

In der erwähnten Arbeit von Buch, Harvey, Wattenberg, Gripenberg sind teils Anweisungen zur Berechnung, teils Tabellen und ein Interpolationsdiagramm zur direkten Entnahme der Kohlensäurekonstituenten für Wasser im Oberflächenzustande gegeben. Für Wasser in der Tiefe werden dort auch die wichtigsten Resultate der vorliegenden Untersuchung angeführt.

Um eine Vorstellung davon zu geben, mit welchen Beträgen sich die verschiedenen Kohlensäurekonstituenten bei zunehmender Tiefe ändern, haben wir dieselben für zwei Oberflächenwerte des pH 7.6 und 8.0 eines Wassers von $t = 0°$, $Cl = 19.5\ ‰$ und Titr.-Alk. $= 2.40$ m Äqv/L berechnet. (Tabelle 5.) Die Konzentrationen sind in Millimolen pro Liter angegeben.

Wie ersichtlich ist die Veränderung in pH recht bedeutend, besonders

Tabelle 5.

$t = 0°$ $Cl = 19.5\ ‰$

Tiefe Meter	pH	Titr.-Alk.	$c_{\Sigma CO_2}$	c_{CO_2}	$c_{HCO_3'}$	$c_{CO_3''}$
0	8.00	2.40	2.23	0.026	2.00	0.20
5000	7.89	2.45	2.27	0.020	2.05	0.20
10000	7.78	2.50	2.31	0.015	2.09	0.20
0	7.60	2.40	2.38	0.074	2.22	0.09
5000	7.44	2.45	2.43	0.063	2.29	0.08
10000	7.27	2.50	2.48	0.052	2.36	0.07

bei niedrigem pH. Diese Tatsache spielt für die Beurteilung der Kalklöslichkeit in den grossen Tiefen eine wesentliche Rolle. Hand in Hand damit geht ein Abnehmen mit der Tiefe der Konzentrationen der freien Kohlensäure und der Karbonationen, sowie ein Steigen derjenigen der Bikarbonationen. Die kleinste Veränderung erfahren jedoch die Karbonationen, deren Konzentration wenn $pH > 8$ in allen Tiefen praktisch dieselbe ist.

Summary.

Until now the carbonic acid equilibrium of sea-water has been studied only for surface conditions. An investigation by E. Brander of the influence of high pressures on the dissociation constants of carbonic acid renders it possible to calculate pH and the various carbonic acid constituents *in situ* at great depths. Brander's results are given in Table 1 and Fig. 1, showing the factors to be applied to the dissociation constants at normal pressure to give those at higher pressures. The second dissociation step, the dissociation of the bicarbonate ion, has not been studied, but as all weak acids behave very similarly, the values for acetic acid can be used. The values in Table 1 have been recalculated by the authors and entered in Table 2, giving the depths in metres and the corresponding amounts to be subtracted from pK_1 and pK_2, the negative logarithms of the constants. Equations 1), 2), 3) and 4) determine the equilibrium of a water sample at any temperature, salinity or depth when the proper values for Kc_1 and K_2' are used. The influence of salinity and temperature is discussed in detail in a shortly to be published paper by Buch, Harvey, Wattenberg and Gripenberg. Equation 8) gives total CO_2 expressed in terms of pH, alkali reserve, K_{c_1} and K_2'. Equation 10) is the same in reduced form, where $A = \frac{c_{\Sigma CO_2}}{\text{alkali reserve}}$. The

equilibrium of a water sample brought up to the surface from a great depth will be displaced as the pressure diminishes; this, however, will not affect the total CO_2 nor the alkali reserve. The only change which these quantities undergo is that caused by the increase in volume of the water sample. The quantity A will remain quite unchanged. This enables us to calculate the change in pH. From equation 10) the quantity A is calculated for a given pH at the surface using the surface values for K_{c_1} and K_2' (to be found in the above mentioned paper by BUCH and co-workers). With this value of A and those of K_{c_1}- and K_2' for the depth in consideration the same equation gives pH at this depth. The difference, ΔpH, between pH at the surface and at a given depth varies with pH. Fig. 2 shows the variation, at a depth of 10,000 metres, of ΔpH with pH at the surface, calculated for a water of 19.5 $^0/_{00}$ Cl and the temperatures 0° and 5°. At low pH values (< 6.5) ΔpH is equal to ΔpK_1; at high values (> 8.5) it equals ΔpK_2. Fig. 3 gives the variation of pH with depth for the same water. The variation from 0° to 5° at pH 7.5 is only 0.02; the salinity influence is still less, for at pH 7.5 the difference between ΔpH at Cl 19 $^0/_{00}$ and 20 $^0/_{00}$ only amounts to 0.01. Table 3 gives the values of ΔpH to be subtracted from the surface pH for an increase in depth of 1,000 metres. When pH at the depth is known, c_{CO_2}, $c_{HCO_3'}$ and $c_{CO_3''}$ can be calculated from equations 5), 6) and 7). For the alkali reserve the value *in situ* should be used. This is found by means of Table 4, which gives the relation s_m/s_0 at various depths between the specific gravities of a water (19.5 $^0/_{00}$ Cl, mean temp. of the water column 5°) at m and 0 metres. In Table 5 the calculation outlined above is carried out for a water of Cl 19.5 $^0/_{00}$, t 0°, alkali reserve 2.40 milli-eq./litre and pH 7.6 and 8.0 at the surface. The concentrations of the carbonic acid constituents at 5,000 and 10,000 metres are given. The table shows that the change in pH with depth is considerable, especially in the case of the acid water. This fact should be taken into account in discussing the solubility of calcium carbonate in deep waters. With increasing depth there is, moreover, a notable rise in the concentration of the bicarbonate ions, but a decrease of the free carbon dioxide and of the carbonate ions. The latter undergo the least change, as above pH 8 the carbonate ion concentration is practically the same at all depths.

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Changes in the Nitrite Content through the Year in North-Norwegian Fjords.

By

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During the monthly hydrographical investigations in the fjords in the neighbourhood of Tromsø, determinations of nitrite-nitrogen have been made regularly from October 1930. The nitrite content of sea-water has been investigated by several students, as, e. g., Buch (1923, 1929), Orr (1926), Brandt (1927), Giral (1929), Giral et Ibanez (1930), Atkins (1930), Wattenberg (1931), and Klem and Braarud (1931). Brandt (1927) has compiled all available data from earlier works. In later years all have used the method of Griess-Ilosvay. The method has been specially studied by Buch with regard to influences of various kinds on the results. I have used the method in the following way:— To abt. 100 ccm. of sea-water 4.5 ccm. of the reagent was added and the samples allowed to stand for one hour in the dark at room temperature. The readings were then made in the Sund colorimeter (Journ. Cons. Int. VI.:2). Standard solutions were made of purest KNO_2 diluted as necessary before use and controlled by standard solutions of freshly precipitated $Ag\ NO_2$ after Treadwell. The colour developed in this way is strong, in order to obtain good readings of even very small quantities, and the elaborate operations at higher temperatures in water-baths are omitted. Some experiments were made to find the accuracy of the method, the influence of temperature, quantity of reagents, and duration of time from the addition of the reagents to the reading. Between the intervals 6° and 36° no appreciable difference was found, while Buch found that lower temperatures gave lower readings. If two pipettes of reagents, 9 ccm. instead of 4.5 ccm., were added, a slight difference was found; small differences in the quantities of reagents seemed to have no affect on the

strength of the colour developed. The colour was also only a little darker after two hours than after an hour, showing that small intervals of time have no influence on the results. The degree of accuracy with a suitable wedge is about 0.1 mg/m³. Even smaller amounts than 0.1 mg/m³ are observable, but are not determined. In the first months the accuracy of

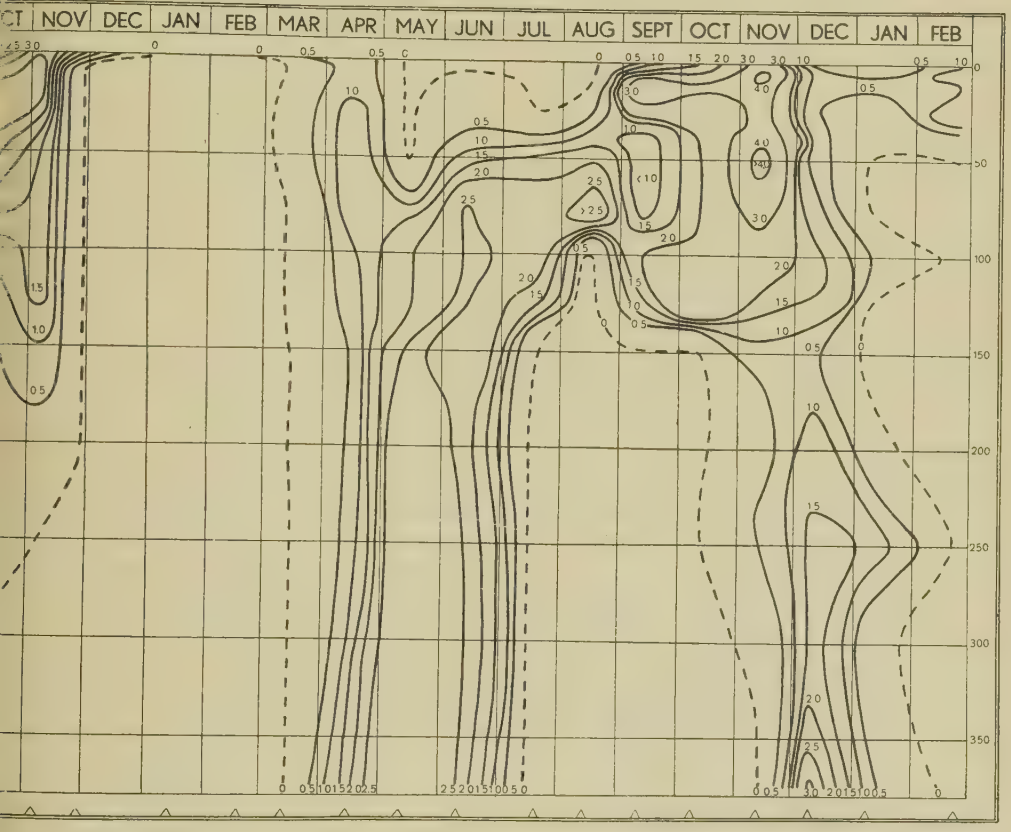

Fig. 1.

the determinations was only 0.2—0.3 mg/m³ and amounts below the same quantities were difficult to read exactly. In some cases where the amounts of nitrite were thought to be very low, 2.5 mg/m³ was added to the samples. The samples ought to be determined as soon as possible, as the content rapidly diminishes if the samples are stored.

As examples of the yearly variation in Nitrite-N, two stations are chosen, viz.: Malangen 8 a, 69°32.8′ N. 17°59.5′ E., an open fjord with rather warm and salty water in the bottom layers, and Balsfjord 5, 69°21.8′ N, 19°6,5′ E., a barred fjord with colder water of lower salinity.

The values are shown in the two isopleths Figs. 1 and 2, where isolines for each 0.5 mg/m³ nitrite-N are drawn from October 1930 to February 1932. The dotted lines circumscribe areas where no nitrite was observed. From March 1931 the determinations are of a greater accuracy than for the first five months.

For the station in Malangen M 8a (Fig. 1) we find rather high values in October-November 1930 downwards to about 150 m. with a maximum in the uppermost 50 m. of more than 3.5 mg/m³, highest value 3.8 mg/m³. In the deeper parts no nitrite was found. From late November to the middle of March no nitrite was observed from bottom to surface, the winter minimum, but as the lower limit for the determinations was about 0.2—0.3 mg/m³, small traces may have been overlooked. From March when the plankton has begun to grow, the nitrite content rises rapidly both at the surface and from the bottom. The spring maximum of more than 2.5 mg/m³ is first met with at the bottom towards the end of April and lasts to the middle of June, the duration being longest at about 100 m. towards the end of June. In the middle of May the surface layers down to 50 m. are completely exhausted of nitrite. This condition of the surface layers lasts to the end of August. In the deeper layers the amount diminishes and all nitrite has disappeared by the middle of July from 100—150 m. downwards. The summer minimum lasts to November. From September to November we met in the uppermost 140 m. a new maximum, the autumn maximum, with a maximal value of 4.2 mg/m³. In the deeper parts the autumn maximum is found later, from the end of November to the end of December with highest values at the bottom. From January 1932 we find the winter minimum again, about a month later than the preceeding winter. For the station in Balsfjord, B 5 (fig. 2), we find similar conditions. In October 1930 we have values above 1.0 mg/m³. From November to March we have a winter minimum with values of less than 0.5 mg/m³ with nitrite-free water the most part of the time. From March the content rises in the surface and later from the end of May in the deeper layers. This maximum with a highest value of 8.3 mg/m³ lasts till the middle of August in the deeper parts. In the surface layers we again find nitrite-free water till mid-September. Then the content rises to more than 3.0 mg/m³. in October and more than 2.0 mg/m³ at the bottom in November. In the middle of January we find the winter minimum again. The isolines follow similar courses on the other stations in the district.

It seems thus that two maxima and two minima occur in the nitrite content through the year, a winter minimum and a summer minimum earlier in the surface than in the deeper layers, and a spring and an autumn maximum beginning nearly at the same time as the corresponding maxima

in the plankton. Some irregularities are probably due to the movement of the water.

The values found by me are in good accordance with the values obtained by other students. Orr (1926) found values from less than 1.0 mg/m³ to about 10 mg/m³ during the summer and he found that the values in the Clyde Sea Area were greater in the bottom layers than in the surface layers. The depths investigated are, however, decidedly smaller than in the two North-Norwegian fjords mentioned above. Atkins (1930)

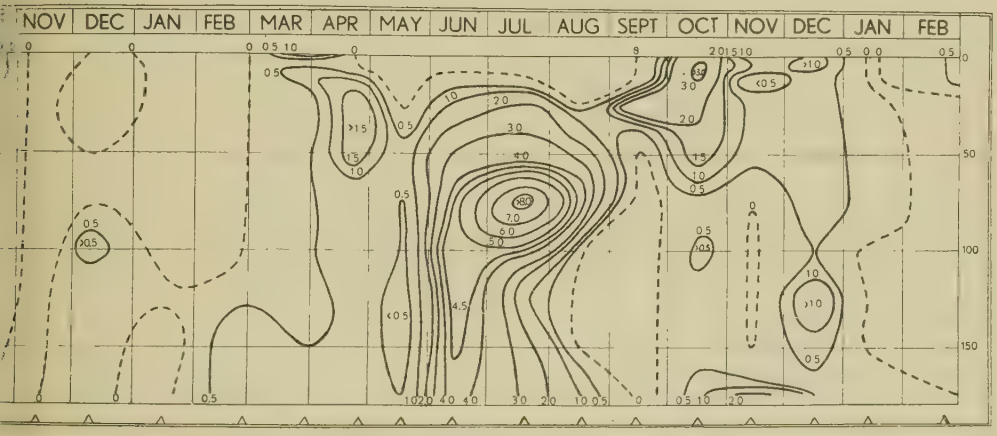

Fig. 2.

found very much higher values than I observed, up to 38.9 mg/m³, while Klem and Braarud (1931) only found values below 4 mg/m³.

The values from which the isopleths are drawn will be published in the "Årshefter" of Tromsø Museum, together with the other hydrographical data. I hope that a correlation of the nitrite values with ammonia and nitrate values for the same stations and of the whole area will give us new information which will help to a further understanding of the nitrogen compounds in sea-water.

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Tunny (*Thunnus thynnus* L.) in the North Sea.

By

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The following notes make no pretence at scientific knowledge, but are merely the notes of a "field" naturalist who has spent the greater part of the last nine years with the trawling fleets round about the Dogger Bank.

When I first came to sea in June 1923 I was constantly being told of the vast numbers of "sharks" that had been seen during the summer of 1922. On August 1st while sitting in my cabin I was called on deck to see the first "shark" of the year, and thus obtained my first view of *Thunnus thynnus* in its native element. From that date until the end of September tunny were present in good numbers daily, coming right up to the ship's side and cleaning up all the small fish which escaped from the trawl or were subsequently thrown away. So tame were they that they could be touched with a boat-hook without difficulty. Having a rifle aboard I shot several specimens and two were picked up in our trawl. Their lengths were 7 ft. 6 ins. and 7 ft. 3 ins., while their girths were 5 ft. 2 ins., and 5 ft., respectively.

Since 1923 tunny have been present in greater or less numbers each summer. The numbers have varied a good deal, the peak year being 1923; 1924, '25 and '26 were good years, but since '26 the numbers have been decidedly decreasing, 1931 being far the poorest. I have often wondered at the factors governing the presence of these fish, and as far as my own observations have gone, their presence depends very much on the supply of mackerel. 1927 was a good herring year, at least on the Dogger, yet tunny were nothing like as numerous as in 1926, when herring was scarce. Mackerel, on the other hand, were numerous in 1926, but since that year have become scarcer.

Since reading M. Le Gall's article on tunny, and learning therefrom

of the influx of Atlantic waters into the North Sea, I can strongly endorse his opinion that this is a tremendous factor in the abundance of these fish. In 1929 and '30, we saw few herring and hardly any mackerel at all, yet tunny were present in moderate numbers, so that the food supply cannot be the only factor governing their appearance.

The photographs illustrating these notes were taken of fish attracted

Fig. 1.

to the ship by fish thrown in from the pound after gutting the catch. The erection of the anterior dorsal fin seems to be a sign of excitement, as I have watched fish swimming beside the ship for hours and never once seen the fin erected until food was thrown in, when everything became a turmoil as the tunny raced for dead fish. A tunny's capacity for food is amazing; a scarred tunny once took 89 mackerel in succession, the supply then becoming exhausted.

There appears no reasonable doubt that the 1922 "shark" plague mentioned by fishermen and reported in newspapers, was the first appearance of tunny in any numbers[1]). I have spoken to dozens of fishermen who have

[1]) Tunny have been observed in the North Sea in autumn by the English fisheries staff on many occasions since 1912. — *Editor.*

spent the greater part of their life in the trawling fleets (Gamecock and Red Cross) and none of them can remember seeing tunny prior to 1922. I doubt if any reliance can be placed on such information, as fishermen, at least in my experience, are singularly unobservant of any life, bird or fish, that does not directly affect their livelihood.

I have never personally observed tunny south of 53°40′ N. Lat., but

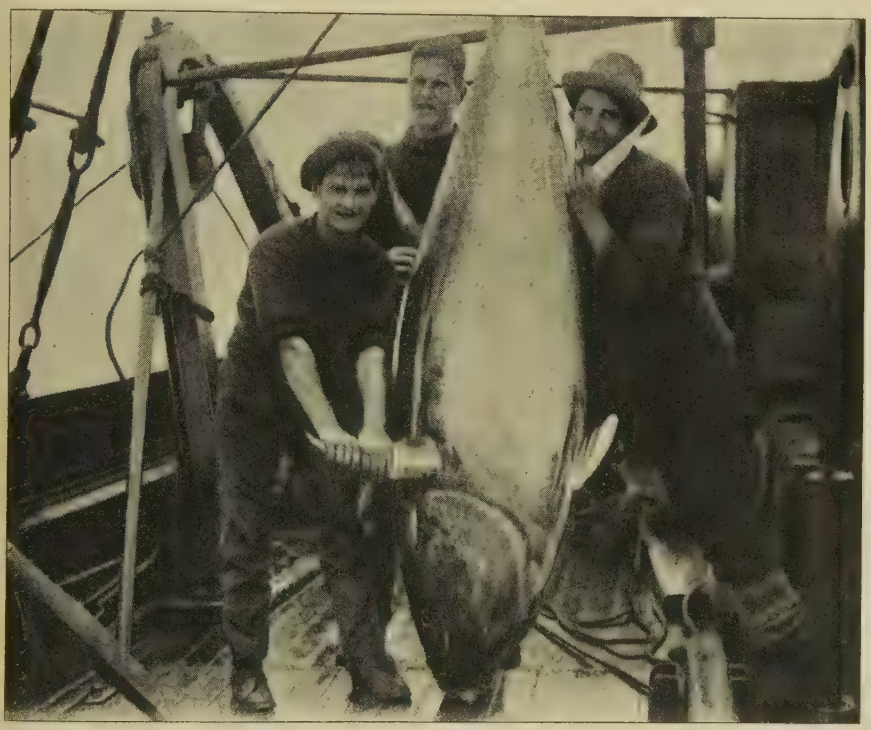

Fig. 2.

our own presence in those latitudes has been purely when running in or out to the fleet. That some difference in either water or the marine life does exist at about 54° N. Lat. seems highly probable, as the Fulmar Petrel's extreme southerly limit appears to be 54°20′ N. Lat., south of which point I have never once seen one.

Tunny appear to be more numerous far from shore than in the coastal waters, as when leaving the fleet they will accompany the ship for perhaps the first hundred miles, but thereafter dwindle in numbers and soon depart. While in the fleet every trawler has an escort of fish varying in numbers, according to their abundance. During 1923, I frequently counted as many as 30 fish swimming alongside, and every vessel in the fleet had a similar escort.

The following table gives a list showing the first and last dates on which tunny were observed each year. The fish noted on 1st Nov. 1929 was an isolated example, no fish having been seen for twelve days previous to this date.

Year	1st Appearance	Last Appearance
1923.....	Aug. 1st	Oct. 10th
1924.....	July 17th	Sep. 30th
1925.....	- 20th	Oct. 3rd
1926.....	- 29th	- 1st
1927.....	Aug. 2nd	- 12th
1928.....	- 1st	- 7th
1929.....	July 17th	Nov. 1st
1930.....	- 19th	Sep. 26th
1931.....	- 20th	- 29th

A Selected Bibliography of Fish Behaviour.

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Preface.

The behaviour of fish is a subject of great importance in connection with the scientific study of fisheries; the literature concerning it is scattered through zoological, physiological and psychological journals, and is neither well known nor, in many instances, easily accessible to the fishery biologist. It has been thought desirable, therefore, to bring together in a convenient form a selection of the main titles relating to fish behaviour, up to and including 1931.

A certain restriction of the scope of the bibliography has been found necessary. With some exceptions, the following classes of papers have been excluded — purely physiological papers, papers relating to fishery investigations, and observations on the special habits of fish. In general, the aim has been to include all experimental work on the behaviour of fish, and to omit other references except where they appeared to be of special interest. Some general references are, however, included (see Section 2 of the Classified List).

For additional titles, of a general nature, reference should be made to the invaluable work of Bashford Dean — "A Bibliography of Fishes", 3 Volumes, American Museum of Natural History, New York, 1916—1923. For subsequent years, the usual general bibliographies should be consulted, e. g. Zoological Record, Bibliotheca Zoologica, Biological Abstracts, Physiological Abstracts, Psychological Abstracts.

The abbreviations used in this bibliography are those of the "World List of Scientific Periodicals" (London 1925, 1927).

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Classified List.

1. Methods.

Abderhalden, in course of publication. Anon, 1930 (a), 1930 (b). Chidester, 1921. Hamilton, 1922. Reighard, 1908 (1910) (a), 1908 (1910) (b). Shelford, 1929. Szymanski, 1914.

2. General.

1. GENERAL NATURAL HISTORY.

Alcock, 1902. Beebe, 1926, 1928. Calderwood, 1930. Carter and Beadle, 1930.Damant, 1920. Day, 1881. Dean, 1896. Deraniyagala, 1929. Gill, 1908 (1910). Graham, 1931. Gurley, 1902. Herrick, 1919. Huet, 1904. Jeannel, 1926. Kyle, 1926. Lahille, 1926. Leiner, 1931. Leonardt, 1909. Lepinay, 1909. Lubbock, 1888. Lydell, 1902. Meek, 1930. Menzies, 1925. Needham and Lloyd, 1916. Norman, 1931. Parker, 1907, 1908. Pearce, 1926. Pycraft, 1912. Regnard, 1891. Romanes, 1883. Rose, 1929. Roule, 1914, 1922, 1926—. Rutter, 1902, 1902 (1904). Sanford, 1903. Shufeldt, 1900. Shelford, 1911, 1912, 1913, 1914 (a), 1914 (b), 1929. Thorndike, 1899. Ward, F., 1911, 1919. Ward, H. B. and Whipple, 1918.

2. GENERAL OBSERVATIONS OF BEHAVIOUR IN CAPTIVITY.

Auer, 1909. Bateson, 1889—90 (a), 1892. Bolau, 1905. Boulenger, 1929. Brehm, 1871. Brown, E. M. 1929. Elmhirst, 1902, 1912. Miles, 1931. Piéron, 1914. Schmidtlein, 1879. Townsend, 1929. Wunder, 1927 (1928), 1930.

3. WORKS ON COMPARATIVE PHYSIOLOGY AND PSYCHOLOGY, ETC. CONTAINING INFORMATION ON GENERAL BEHAVIOUR OR SENSORY REACTIONS OF FISHES.

Baglioni, 1912, 1913. Buddenbrock, 1924. Buytendijk, 1918, 1928. Dambeck, 1878. Fiebriger, 1923. Goldsmith, 1924, 1927. Gurley, 1909. Haempel, 1912. Hempelmann, 1926. Herrick, 1924. Hogben, 1926. Holmes, 1911. Johnston, 1906. Kafka, 1922. Koehler, 1920, 1922, 1924, 1926, 1928. Kuhn, 1919, 1925. Loeb, 1905, 1913. Plate, 1924. Reighard, 1903, 1917. Watson, 1914. Washburn, 1926. Vincent, 1914. Uexküll, 1905.

3. Sensory Discrimination.

1. CHEMICAL SENSE.

(a). Reactions to Salinity: Hydrotaxis: Chemotaxis: Reactions to non-sapid substances.

Bull, 1928. Calderwood, 1891—2. Chaper, 1883. Chidester, 1920, 1922, 1924. Crozier, 1916. Dahl, 1904. Daugherty and Altman, 1925. Franz, 1909. Garrey, 1916.

Herter, 1926, 1927. Loeb, 1912, 1913 (a). Miles, 1918. Parker, 1912. Quigley, 1928. Shelford, 1909. Shelford and Allee, 1914. Sumner, 1905 (b). Wells, 1915 (a). Young, 1923.

(b) Reactions to Pollution: Effects of Oxygen Deficiency or Excess, Acidity, etc.

Birge and Juday, 1911. Brown and Jewell, 1926. Bull, 1930 (1931), 1931. Das, 1927. Daugherty and Altman, 1925. Foerster, 1929 (a). Gardiner, 1927. Gardner, 1926. Gardner and Leetham, 1914. Garrey, 1926. Gutsell, 1929. Heldt, 1926. Huet, 1904. Jackson, 1930. Jewell and Brown, 1924. (See also Brown and Jewell.) Juday and Wagner, 1908. Loeb, 1912. Marsh, 1908. Miles, 1918. Packard, 1905. Powers, 1917, 1921. Richet and Oxner, 1926. Roule, 1914, 1915. Roule and de Drouin de Bourville, 1927. Shelford, 1913, 1914, 1915, 1917, 1918, 1923, 1929. Shelford and Allee, 1912, 1913, 1914. Shelford and Powers, 1915. Thompson, 1925. Wells, 1913, 1915, 1918. White, 1915. Young, 1923.

2. OLFACTION.

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Bull, 1928, 1930 (a). Hathaway, 1927. Herter, 1925, 1926. Loeb and Wasteneys, 1912. Lumby and Atkinson, 1929. Michael, 1907. Miles, 1918. Thompson, 1926. Wells, 1914.

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Galvanotaxis.

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Bettoni, E., 1867. Dankler, 1899, 1902.

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Apgar, 1886—8. Arey, 1919. Barton, 1930. Bateson, 1889—90 (a). Bowen, 1931. Bull, 1928. Clausen, 1931. Dudgeon, 1871. Garrey, 1905. Graham, 1931. Gurley, 1902. Harding, 1931. Herter, 1929, 1930. Frisch, 1925. Lanik, 1914. Longley, 1923, 1924. Plateau, 1866. Reinhardt, 1902. Rizzolo, 1926. Russell, E. S., 1931. Schaller, 1926. Schultze, L., 1915. Spooner, 1931. Stagner, 1931. Steven, 1930. Trojan, 1914. Tschermak, 1902, 1914, 1915. Verrier, 1927, 1928, 1929 (a). 1931 (a), 1931 (b). Viguerron, 1913. Weve, 1913. White, 1919. Wood, 1906 (a), (b). Zezula, 1909.

Reactions to mirror images.

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Baglioni, 1913. Clark, 1925. Clausen, 1931. Daugherty and Altman, 1925. Franz, 1910 (a), 1910 (b). Garrey, 1905. Gurley, 1902. Herter, 1925, 1926. Hofer, 1907. Hunt, 1885. Huntsman, 1918. Jackson, 1930. Jordan, 1917 (a), 1917 (b). Kafka, 1922. Kreidl, 1895. Lee, 1898. Loeb, 1913. Lyon, 1900, 1904 (1905), 1905, 1909. Main, 1927. Mangold, 1913. Michael, 1907. Miles, 1918. Parker, 1904, 1905. Rutter, 1902, 1904. Schiemenz, 1927. Shelford, 1914 (a), 1914 (b). Smirnov, 1924. Steinmann, 1914 (a), 1914 (b), 1928. White, 1915. Chidester, 1921, 1922. Tullberg, 1903.

4. SHOALING.

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Bull, 1929 (1930), 1930 (1931), 1931. Chevey, Roule, and Verrier, 1927. Chidester, 1920, 1921, 1922, 1923, 1924. Clark, 1925. Craigie, 1926. Foerster, 1929 (a), 1929 (b).

Franz 1909, 1910 (b), 1910 (e), 1912 (a). Gardner, 1926. Garrey, 1916. Greene, 1926. Gregory, 1929. Gurley, 1909. Jaeger, 1911. Juday and Wagner, 1908. Kühn, 1919. Künstler, 1913. McDonald, 1885. Mast, 1915. Meek, 1916. Petersen, 1906. Powers, 1921. Prince, 1920. Rich and Holmes, 1928. Roule, 1914, 1915, 1916, 1922, 1926. Roule and de Drouin de Bourville, 1927. Rowan, 1926. Scheuring, 1929, 1930. Waltoniensis, 1931. Ward, 1927, 1930. Willis-Bund, 1902.

5. Other Reactions of the Organism as a whole.

1. FOOD FINDING.

Bateson, 1889—90 (a), 1892. Buytendijk, 1919. Chadwick, 1929. Cronheim, 1911. Damant, 1921. Drzewina, 1909. Elmhirst, 1909. Franz, 1909—10. Herrick, 1902. Hughes, 1891—2. Knight, 1910. Lebour, 1916—18, 1919—22, 1923—25. Lepinay, 1907. Mellen, 1927. Pipping, 1927 (a), 1928 (b). Scheuring, 1921. Schiche, 1921. Schiemenz, 1928. Steven, 1930. Uexküll, 1895. Wilson, 1893. Verrier, 1929 (b). Wunder, 1927, 1928, 1929.

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Buytendijk, 1930. Franz, 1913 (b). Lebour, 1923—5. Mast, 1915.

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Bordage, 1911. Connolly, 1925. Cunningham, 1891, 1893—5, 1895—7. Cunningham and MacMunn, 1893. Frisch, 1911 (b), 1912 (b), 1912 (c), 1913 (a). Fukui, 1927. Haempel and Kolmer, 1914. Hewer, 1926 (a), 1926 (b). Hogben, 1926. Jost, 1926. Kunst, 1917. Kurz, 1920. La Blanchère, 1872. Loeb, 1912. Longley, 1917, 1924. Mast, 1915 (a), 1915 (b), 1916. Miles, 1918. Pauli, 1926. Pouchet, 1871, 1873. Reighard, 1908 (1910), 1909. Rynberk, 1906. Schoendorff, 1903. Schnakenbeck, 1925. Schnurmann, 1920. Secerov, 1909, 1913, 1914. Stark, 1832. Sumner, 1905 (a), 1910, 1911 (a), 1911 (b). Sumner and Keys, 1930. Townsend, 1929. Verrier, 1929 (b).

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Anon, 1910. Athanassopoulos, 1931. Bateson, 1889—90 (a). Bauer, 1904. Braunschmid, 1930. Bull, 1928, 1929 (1930), 1930 (a). Buytendijk, 1918, 1919, 1928. Buytendijk and Remmers, 1923. Cason, 1925. Churchill, 1916. Crivelli-Serbelloni, 1900. Dankler, 1902. Dantan, 1902. Demoll, 1921. Edinger, 1899. Faraday, 1879. Franz, 1912 (a), 1912 (b), 1913 (a). Frisch, 1923, 1925. Froloff, 1925, 1926, 1928. Giard, 1897, Goldsmith, 1905, 1912, 1924, 1927. Hanko, 1925. Herter, 1929, 1930. Holmes, 1911. J. J., 1897. Landois, 1897. Lepinay, 1907. Longley, 1923, 1924. McDonald, 1922. McIntosh, 1898. Meek, 1930. Mellen, 1930. Milner, 1880. Minkiewicz, 1912. Möbius, 1873. Morgan, 1924. Oxner, 1912 (a—e). Parker, 1903, 1909. Parville, 1897. Perkins and Wheeler, 1930. Perkins, 1931. Piéron, 1908, 1910, 1914. Reeker, 1898. Reighard, 1908, 1917. Rich and Holmes, 1928. Rivera, 1905. Roule, 1926. Russell, E. S., 1931. Schwarz, 1911. Snyder and Scofield, 1924. Stetter, 1928, 1929. Thierfelder, 1911. Thorndike, 1899, 1911. Triplett, 1901. Uhlenhuth, 1911. Washburn and Bentley, 1906. Welty, 1930. Westerfield, 1922. White, 1919. Wolff, 1925. Zur Mühlen, 1911.

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Paton, 1907, 1911. Tracy, 1925, 1926. White, 1915. Wintrebert, 1920.

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Reviews.

Alphonse Berget. Leçons d'Océanographie Physique: 2me partie: L'Océan et l'Atmosphère. Ann. de l'Inst. Océanogr. N. S., Tome XI, pp. 396, 193 figures. Paris, 1931.

This is the second part of Professor BERGET's treatise on physical oceanography. Like the first part (Tome IX of the same series), it is an eminently clear exposition of the matters dealt with. It is illustrated adequately, for the drawings and diagrams, though rough, are sufficient for their purpose. Chapters I to IV deal with the chemical and optical characteristics of the atmosphere; Chap. V with solar radiation and Chaps. VI to XI with winds and the general physics of the atmosphere. Chaps. XIV to XVII again deal with winds, storms and other atmospheric movements, by themselves and in relation to oceanic drifts and currents. Chap. XVIII treats of climate as it may be related to oceanographic matters. The rest of the book has for its subject currents and drifts, their descriptions and the methods by which they are investigated. Forms of apparatus for the elucidation of the directions and intensities of water movements in the ocean are not well described. (For instance, well-known methods and apparatus devised by CARRUTHERS do not receive notice). Nor are the actual descriptions of current systems adequate. On the scale adopted by the author these water movements appear to be far too simple and the real complexities which any detailed investigation of a small region shows are not mentioned. Such a course of lessons in oceanographical science as this ought to suggest (at least) that natural conditions, as they are known to investigators, are far more complex, and more difficult of exposition, than they appear to be when they form the subject-matter of a course of lectures. JAS. JOHNSTONE.

G. Böhnecke. Beiträge zur Ozeanographie des Oberflächenwassers in der Dänemarkstrasse und Irminger See. Teil I, zugleich Bericht über die Fahrt des "Meteors" im Sommer 1930. Annalen der Hydrographie u. s. w. LIX Jahrgang (1931), Heft IX. Berlin, 1931.

In 1928, 1929 and 1930 the German surveying ship "Meteor" was used for oceanographical investigations in the Denmark Strait and Irminger Sea between Iceland and Greenland. In 1928 J. GEORGI made observations on a voyage from Reykjavik to the neighbourhood of Angmagsalik, round the southern part of Greenland to Julianehaab and back to Reykjavik.

In 1929 different hydrographical investigations were made from the ship by the scientists Dr. Böhnecke, Prof. Hentschel, cand. phil. Geissler, Dr. Thorade and Dr. Wattenberg on four sections between about 60° and 65° N. Lat., and 25° and 40° W. Long. In 1930 the investigations were continued by Dr. Böhnecke, Prof. Defant, cand. phil. Felber, Prof. Schulz and Dr. Weickmann on two sections from Reykjavik to about 55° N., 35° W., and on two sections from this area to the southernmost part of Greenland.

In the present paper G. Böhnecke discusses the surface observations from the three years' work and the paper is a continuation of an earlier one by G Böhnecke, E. Hentschel and H. Wattenberg in Ann. d. Hydr., 1930.

The author first tries to obtain a general view of the relation between temperature and salinity for each of the years in question by means of TS-diagrams based upon surface material from the whole of the investigated area. The diagrams show clearly the mixing of the Atlantic water with that of the East Greenland current, but it is found that the diagrams are different in different years. As the author says, this may be partly due to the fact that the area investigated in the different years has not been the same. The diagrams for all three years have the same form but are not straight lines, and probably their characteristic shape is due to the atmospheric influence, which may cause an exchange of heat between the Atlantic water and the water of the East Greenland current (and the Greenland land-mass) without a mixing of the waters.

The author has drawn charts of mean temperature and mean salinity for the month of August for the investigated area and made an analysis of the different sorts of water existing there. The Atlantic water is mainly found east of the Reykjanes ridge, which the echo-soundings of the "Meteor" have shown to be of larger extent than was hitherto thought. Of special interest is the mixing between the Atlantic and the polar water. The Atlantic water passes the northeastern part of the Reykjanes ridge near Iceland, penetrating into the Denmark Strait. Here it meets the polar water of the East Greenland current, and the two sorts of water form the "arctic mixed water" on a sinuous "Polar Front" lying between Iceland and Greenland, off Angmagsalik, and along the east coast of Greenland.

South and east of Cape Farvel relatively homogeneous water with temperatures from 8° to 9° and salinities from 34.5 to 34.8 ‰ is found. The author calls this water the "subarctic mixed water", which is supposed to have been formed by a mixing of Atlantic water, of water formed by mixing at the polar front and moving along the Greenland coast, and finally of some water from the Labrador current. At about 50°—51° N. this subarctic mixed water has a front to the Atlantic water south of it, which Defant in his treatment of these investigations by the "Meteor" calls a "secondary polar front".

On the basis of the charts of mean temperature and salinity the author has constructed a chart showing the average movement of the water in the investigated area. This movement may in the main be characterized as cyclonal.

At the polar front in Denmark Strait Atlantic water and polar water

are forced into one another, and various "tongues" of the two sorts of water are formed. The same thing occurs on the boundary between the subarctic and the Atlantic waters in the southern part of the area.

It is of interest to see that these tongues are found on the charts of mean values and may therefore be supposed to have to some degree a stationary character. The author himself mentions the fact that the method of deducing the currents from the distributions of temperature and salinity involves some uncertainty, as has also been pointed out recently by CASTENS. This question has just been discussed by DEFANT in his treatise on the "Meteor" investigations in the Denmark Strait and Irminger Sea, and, as he states, the mean general features of the currents may undoubtedly be found in this way. As DEFANT also points out, BÖHNECKE's chart is in good agreement with the hypothetical picture of the currents which has been given by NANSEN.

Besides the results so far mentioned special questions relating to the different years are also discussed. The question of the formation of the bottom water is touched upon, but it is remarked that a further contribution to the solution of this problem cannot be given before the material from the depths has been worked up. J. P. JACOBSEN.

Trygve Braarud and **Alf Klem.** Hydrographical and Chemical Investigations in the Coastal Waters off Møre and in the Romsdalsfjord. Norske Videnskaps-Akad. i Oslo. Hvalrådets Skrifter, Nr. 1. Oslo, 1931.

Die Arbeit erscheint als erste Nummer einer Serie von Veröffentlichungen, welche sich mit denjenigen physikalischen, chemischen und biologischen Faktoren beschäftigen soll, die für die Schwankungen im Vorkommen der wirtschaftlich wichtigen Lebewesen des Ozeans verantwortlich zu machen sind. Seit 1925 werden unter Leitung von Prof. J. HJORT und Prof. H. H. GRAN von der Walfangstation Aukra bei Molde aus hydrographische und biologische Untersuchungen längs eines Schnittes senkrecht zur Küste angestellt. In den letzten Jahren wurden in steigendem Masse auch die biologisch wichtigen chemischen Eigenschaften des Wassers studiert. Zu den Sauerstoff-, Phosphat- und Nitrat-Bestimmungen kamen noch Nitrit-, Ammoniak- und Eisen-Analysen hinzu.

Von den terminmässig befahrenen 6 Stationen liegen zwei im Fjord, drei auf dem Schelf und eine auf dem Schelfabfall. Dementsprechend ändert sich der Charakter des Wassers vom salzarmen Fjord über den als Fortsetzung des Baltischen Stroms aufzufassenden Küstenstrom bis zum salzreichen Wasser des Atlantischen Stroms. Die hydrographischen Verhältnisse ausserhalb des Fjords sind für die Jahre 1926—28 bereits von E. MARTENS[1]) beschrieben worden. Die Jahre 1929 und 1930 waren in den Hauptzügen den vorhergehenden ähnlich. Als Grundlage für die Diskussion der Hydrographie diente — wie auch sonst mehrfach in neuerer Zeit — zum grossen Teil die Verteilung des Sauerstoffs. Von den hydrographischen

[1]) Hydrographical Investigations in the Norwegian Sea off Møre 1925—28. Conseil Internat. Rapp. et Proc.-Verb. LVI (1929). Ref. Journal du Conseil Vol. 5, S. 238 (1930).

Ergebnissen mag erwähnt werden die jährliche Erneuerung des Tiefenwassers des Fjords durch Überfliessen von schwerem sauerstoffreichen Wasser aus dem Nordmeer über die Schwelle, durch die der Fjord abgesperrt ist, ferner die besonders instabile Schichtung auf den küstennahen Schelfstationen im Winter, die durch die Abkühlung bedingt und durch langandauernde Seewinde verstärkt wird.

Über die Ausführung der chemischen Bestimmungen werden zunächst einige wertvolle methodische Einzelheiten mitgeteilt. Bei der Nitrat-Analyse nach Harvey wird ein bedeutender Einfluss der Temperatur auf die Geschwindigkeit der Reaktion und auf die Intensität der erreichten Farbe festgestellt. Für die Ammoniakbestimmungen wird mit gutem Erfolge die Methode von Buch und Witting verwendet, die auch in sehr planktonreichem Wasser klare, leicht zu kolorimetrierende Lösungen ergibt. Neu eingeführt wird eine Methode zur Bestimmung des Eisens im Seewasser: 500 ccm Seewasser werden unter tropfenweisem Zusatz von 1 ccm Brom-Salzsäure (1:500) auf 100 ccm eingedampft und nach dem Abkühlen 1 ccm KCNS (50 %) sowie 10 ccm Äther-Amylalkohol (1:1) zugesetzt und umgeschüttelt; dann wird mit bekannten Ferrisalzlösungen verglichen.

Die räumliche Verteilung und der jahreszeitliche Gang der Hauptplanktonnährstoffe lassen sich aus den hydrographischen und biologischen Verhältnissen zwanglos erklären. Die Zufuhr von Nährstoffen von Land und aus den Niederschlägen spielt offenbar keine Rolle im Verhältnis zu den Mengen, die aus dem Tiefenwasser an die Oberfläche gelangen. Die Nitritkonzentration hält sich in den auch sonst beobachteten sehr niedrigen Grenzen. Die Nitritkonzentration wurde von Atkins als Mass für die Intensität der Nitrifikation angesehen. Nun fand aber Braarud in fast allen Wasserproben eine starke Denitrifikation, die erst durch grosse Zusätze von Ammonsalz gehemmt wurde. Dieselbe Beobachtung wurde an vielen Reinkulturen von marinen Bakterien gemacht. Daher kann ein hoher Nitritgehalt nach den Verfassern sowohl ein Anzeichen für Denitrifizierung wie für Nitrifizierung sein.

Sehr bemerkenswert ist die Erklärung, die die Verfasser für das von Gran beobachtete zeitlich stark verschiedene Einsetzen der Frühjahrswucherung des Planktons geben. (H. H. Gran hat die Ergebnisse der biologischen Beobachtungen bis zum Jahre 1929 schon an anderer Stelle veröffentlicht[2]).) Zuerst entwickelt sich das Plankton im Fjord, dann draussen im Atlantischen Strom und erst zuletzt in dem dazwischenliegenden Küstenwasser. Zwei Faktoren sollen nun für das frühere oder spätere Einsetzen der Planktonentwicklung verantwortlich sein: Die Stärke der vertikalen Mischung der Oberflächenschichten durch Wind und Wellen und zweitens die Geschwindigkeit der Strömung. Je stärker die Mischung, desto mehr wird die Planktonentwicklung verzögert, weil die Zellen immer wieder aus der Assimilationszone entfernt werden. Und je grösser die Stromgeschwindigkeit des von Süden kommenden Wassers ist, desto eher setzt

[1]) Investigations of the Production of Plankton outside the Romsdalsfjord 1926—27. Rapp. et Proc.-Verb. Vol. LVI (1929). Ferner The Spring growth of the Plankton at Møre in 1928—29 and at Lofoten in 1929 in relation to its limiting factors. Norske Videnskaps-Akad. Oslo. Mat.-Nat. Kl. No. 5. (1930).

die Entwicklung ein, da das Wasser umso kürzere Zeit vorher erst dem starken Licht der niederen Breiten ausgesetzt war. Dementsprechend beginnt die Planktonwucherung im Frühling einerseits im stillen Wasser des Fjords, und zum anderen in dem zwar stark bewegten, aber schnell von Süden her kommenden Atlantischen Wasser, während sie zuletzt in dem sehr langsam strömenden, intensiv bewegten und durchmischten Schelfwasser eintritt. Mit Recht weisen die Verfasser zum Schluss darauf hin, dass eine umfassende Kenntnis der physikalischen und chemischen Bedingungen die Voraussetzung ist nicht nur für die Beurteilung der Fruchtbarkeit eines Meeresgebietes im allgemeinen, sondern auch z. B. für die Lösung der Frage, was den auffälligen Wechsel in der qualitativen Zusammensetzung des Planktons verursacht. H. Wattenberg.

Charles F. Brooks. Varying Trade Winds change Gulf-Stream Temperatures. Gerlands Beitr. z. Geophys. Bd. 34, Köppen-Bd. III. Leipzig, 1931.

Das Problem des Zusammenhanges zwischen atmosphärischer und oceanischer Zirkulation im Nord-Atlantik, das der Verfasser in zahlreichen früheren Schriften behandelt hat, erfährt hier eine kurze zusammenfassende Darstellung, welche auch viele Hinweise auf die Arbeiten anderer Forscher enthält.

Neu ist eine Umgruppierung der Ergebnisse von Hepworth, welcher die Schwankungen der Stärke des Nordost- und Südost-Passates mit der veränderlichen Lage verschiedener Isothermen im Golfstrom verglichen hatte, einen eindeutigen Zusammenhang aber nicht ermitteln konnte. Indem Brooks schliesst, dass verstärkter Passat durch verstärkte Äquatorialströme zunächst zwar das warme Oberflächenwasser anhäuft, dann aber ein Aufquellen von kaltem Wasser als Ersatz dafür verursacht, kommt er zu viel besserer Übereinstimmung. Er trennt z. B. die Temperatur-Abweichungen des Golfstromes, die verstärktem Nordost-Passat folgen, in zwei Gruppen und findet 3—6 Monate nachher erhöhte Temperatur, 9—11 Monate nachher erniedrigte Temperatur. Dadurch wird unser Einblick in diese bedeutsame Korrelation so verbessert, dass die Aussicht, sie für langfristige Prognosen verwenden zu können, erheblich gestiegen ist. Bei der Bedeutung des Golfstromes für die jährlichen Änderungen der Witterung im gesamten Nord-Atlantik und im angrenzenden amerikanischen und europäischen Festland sind daher die Untersuchungen von Brooks von gleichem Interesse für Meteorologen wie für Ozeanographen. v. Schubert.

A. Defant. Bericht über die ozeanographischen Untersuchungen des Vermessungschiffes "Meteor" in der Dänemarkstrasse und in der Irmingersee. Zweiter Bericht. Sitzungsber. d. Preuss. Akad. d. Wiss. Phys.-Math. Klasse 1931 XIX. Berlin 1931.

In his first report on the observations of the "Meteor" in the Denmark Strait and the Irminger Sea Defant pointed out that a series of whirls are constantly formed along the oceanic polar front, separating the cold water of the Greenland current from the warm Atlantic water. In his second

report he shows that these whirls have a quasi-stationary character because in two successive years they were found in approximately the same locations and still more because they appear in the maps showing the average distribution of temperature and salinity during 40 years.

DEFANT gives a map showing the principal features of the currents in the region to the south of Denmark Strait. The East Greenland current is very narrow and follows the coast, bending towards the north-west after rounding Cape Farvel. Another current carrying water of Atlantic origin runs parallel and along the boundary line separating these currents numerous whirls are formed. To the south of these currents one finds an east-going current which represents a branch of the Labrador current, and still further to the south one meets the east-going Atlantic Drift. Along the boundary separating the two latter whirls are also formed.

This current system has been derived from the distribution of temperature, salinity and density, and DEFANT, therefore, discusses how far one is allowed to draw conclusions as to the currents on the basis of isolines. Theoretical considerations lead to the result that such conclusions are strictly correct only in the absence of turbulence and mixing processes and must, in general, be presented with due reservations.

A valuable result of the work of the "Meteor" is given in the form of a detailed bathymetric map which is based on numerous echo-soundings and shows that the Iceland ridge stretches considerably farther towards the south-west than was previously assumed. H. U. S.

V. W. Ekman. Zum Probleme des Golfstromes. Gerlands Beiträge zur Geophysik, Band 33 (Köppen-Band II), pp. 353—364. Leipzig, 1931.

Studies of the currents in the North Atlantic on the basis of surface observations and on the basis of dynamic calculations have shown that BENJAMIN FRANKLIN's conception of the Gulf Stream as a "river in the sea" is nearly correct. Within an area which stretches from the American coast more than half way across the Atlantic, the Gulf Stream flows as a narrow and swift current. EKMAN now asks why this feature is met with. His considerations lead to the result that the prevailing winds probably are of great importance to the peculiar development of the current. An estimate of the effect of the wind points in the direction that the winds facilitate an accumulation of warm water in the central part of the Atlantic and help to establish a steep temperature gradient in the northern part, thus creating a density distribution which gives rise to a narrow and swift current. The estimate of the effect of the wind is, however, very rough, and EKMAN concludes by stating that the problem is not solved and by urging a systematic investigation of the western North Atlantic. H. U. S.

H. Geissler. Tiefenmessung mit ungeschützten Thermometern. Annalen der Hydrographie, u. s. w. LIX Jahrg. (1931), Heft XII. Berlin 1931.

The method of using an unprotected reversing thermometer in combination with a protected one for determination of the depth was first employed by the German hydrographer E. RUPPIN in 1905, and the method has later been used by various scientists.

The author of the paper under review refers to the different treatises written on the subject and has considered whether it would be possible to simplify the manner of proceeding by applying the correction arising from the differences in density of the sea-water.

The author starts from the supposition that the pressure p in a certain depth z in the sea has been determined most accurately by the method in question, and he then suggests that the error in determination of the depth arising from inaccuracy in determination of the pressure lies between $3.44 + 0.00214\ z$ and $1.20 + 0.00125\ z$ metres.

Based upon the knowledge of the density of the sea-water *in situ* at different depths in the Atlantic at stations between 64° N. and 70° S., an attempt is made to establish a relation between z and p which may be used at all places in the ocean with such an approximation that the errors involved by its use are smaller than the errors arising from the inaccuracy in the method given above.

Such a relation between z, indicated in metres, and the pressure p, expressed in kg/cm², is given in the treatise, partly in the form of a table directly calculated from the actual values of the densities and partly by the formula

$$z = -220525.75 + 10^4 \sqrt{486.316 + 0.042918\ p}.$$

For making up the formula the following relation between the density *in situ* ϱ and the depth z is used:

$$\varrho = 1.02765 + 0.00000466\ z.$$

According to the author this formula represents the actual distribution of the density in the ocean so closely that values of z for a certain value of p taken from the table mentioned or from the formula above only differ by 1 or 1.5 metres.

The relation between z and p quoted above may be written with a sufficient approximation as

$$z = 9.731\ p - 2.15 \left(\frac{p}{100}\right)^2 + 9.5 \left(\frac{p}{1000}\right)^3,$$

from which it is seen that for depths from the surface to 500 m. the two last terms may be disregarded, and that for depths from 500 to 5000 m. the last term may be disregarded.

The determination of p by means of the difference Δt between the "temperatures" indicated by the unprotected and the protected reversing thermometers is found by means of

$$p = \frac{\Delta t}{\alpha}.$$

In this expression special attention must be paid to α, which should be very nearly a constant, but according to the author shows a slight dependence on the age of the thermometer and on the temperature of the water. It should also be mentioned that p, according to its relation to the depth z, must be expressed in kg/cm²., which at different places on the earth is not

an absolute unit, and that α must then be supposed to vary slightly with gravity.

In order to make his scheme for the calculation of depth applicable to more or less enclosed waters, e. g., the Baltic and the Mediterranean, the author has added a graph from which the necessary corrections to the values found in the main table may be taken. J. P. Jacobsen.

T. Gustafson och **B. Otterstedt.** Svenska strömmätningar i Kattegatt 1930. Svenska Hydrografisk-Biologiska Kommissionens Skrifter, ny serie, hydrografi X. Göteborg, 1931.

Im Jahre 1930 wurden in der Gegend vom Feuerschiff "Fladen" im Kattegat zwei Strommessungsserien in verschiedenen Tiefen mittels drei photographisch registrierender Strommesser vom Typus O. Pettersson ausgeführt. Die erste Beobachtungsserie wurde in der Zeit 27. Juli—4. August vorgenommen, wobei die drei Strommesser gleichzeitig in den Tiefen 7.5, 11.5 und 15.5 verankert wurden. Von diesen Strommessern arbeitete jedoch nur der tiefste die ganze Zeit einwandfrei. Während der zweiten Beobachtungsperiode vom 25. Oktober bis 7. November wurden die Strommesser in den Tiefen 11.5, 21.5 und 31.5 m verankert; von denselben arbeitete jedoch der Strommesser in 21.5 m Tiefe nur sehr kurze Zeit, sodass verwendbare Werte nur für die Tiefen 11.5 und 31.5 m vorliegen. Gleichzeitig mit diesen Registrierungen wurden regelmässige Strommessungen und gewöhnliche hydrographische Beobachtungen an Bord des "Fladen" ausgeführt. Um eine Auffassung von der allgemeinen hydrographischen Lage während der Beobachtungstermine zu erhalten, wurden dazu noch mehrere hydrographische Schnitte quer zur schwedischen Küste im Kattegat vom Forschungsschiff "Skagerak" gemacht.

Der Hauptzweck der Strommessungen war, ein Material für weitere Untersuchungen des Windstromes und besonders der Bedeutung der virtuellen inneren Reibung in einem inhomogenen Wasser für die Fortpflanzung des Stromzustandes von der Oberfläche in tiefere Schichten zu erhalten. Die starke Schichtung des Wassers sowie die vertikalen Schwingungen der Sprungschicht und weiter die Störungen infolge der Gezeitenströmungen bewirkten jedoch, dass die Strommessungen zu diesem Zweck nicht besonders geeignet waren. Man beabsichtigt daher, gleichartige Messungen im zentralen Ostseegebiet auszuführen, wo die Gezeitenströmungen von untergeordneter Bedeutung sind und wo auch die Schichtung nicht so ausgeprägt ist wie im Kattegat. Bei der Bearbeitung des Materials ging u. a. hervor, dass die Einwirkung der Schwingungen der verankerten Boje auf die registrierte Geschwindigkeit sehr gering war, sodass die registrierte Stromgeschwindigkeit mit genügender Sicherheit als die wahre Stromgeschwindigkeit behandelt werden konnte. Etwas grösser war dagegen die Einwirkung auf die Richtungsangaben, aber auch diese Störungen sind sicherlich viel kleiner als bei den meisten anderen Methoden.

Durch gewöhnliche harmonische Analyse konnten aus den Stromregistrierungen die Gezeitenellipsen berechnet werden. Es stellte sich hierbei u. a. heraus, dass in derselben Tiefe (11.5 m) grosse Veränderungen zwischen den Gezeitenellipsen der Sommerserie und der Herbstserie festzustellen waren,

was wohl als eine Folge der Veränderung der Schichtung zu deuten ist. Bei der Bearbeitung wurden weiter mehrere wertvolle Beobachtungen über die Einwirkung von Windschwankungen auf die allgemeine Schichtung in den hydrographischen Schnitten gemacht.

In einem Anhang behandelt schliesslich T. Gustafson theoretisch die Frage, wie der Triftstrom sich in einem inhomogenen Wasser entwickelt, wo der Koeffizient der virtuellen inneren Reibung in der Umgebung einer Grenzschicht (Diskontinuitätsfläche) abnimmt. In dem stark idealisierten Falle, dass der Reibungskoeffizient plötzlich in einem bestimmten Niveau auf Null sinkt, wird eine Lösung mit Hilfe der von J. E. Fjeldstad gegebenen Methode ermittelt. Die Lösung zeigt, dass der Triftstrom sich in diesem Falle viel schneller nach unten fortpflanzt als im Falle von homogenem Wasser. Dieses Ergebniss kann in qualitativer Weise der Einwirkung eines mit der Tiefe variablen Reibungskoeffizienten in geschichtetem Wasser beleuchten. — Man wird mit Interesse die Ergebnisse der weiteren Registrierungen in der Ostsee erwarten. E. Palmén.

O. v. Schubert. Zur Frage der Stabilität in grossen Meerestiefen bei Temperaturumkehr. Gerlands Beiträge zur Geophysik. Bd. 31, Heft 4. Leipzig, 1931.

The author deals with the question of the stability at great depths when temperature inversion occurs and treats more especially the conditions in the southern part of the Philippine Trench. He compares the conclusions of Schott and Wüst, based on scattered bottom observations in this region from the "Planet" and those derived from serial observations carried out by the Snellius Expedition in 1930 at the deepest spot on the earth, east of Mindanao (station 262, lat. N. 9°40′5, long. E. 126°50′5), and published in the preliminary reports of the Expedition.

Schott and Wüst estimated from the mean temperature curve that a minimum occurs at 5000 m. and calculated for the layers between 6000 m. and the bottom negative stability values.[1]) The Dutch observations point to positive values with the exception of the layers between 4500 to 5500 m., where a discontinuity occurs. A minimum temperature of 1.585° has been observed in a much higher level, in 3500 m.; from this level temperature increases to 2.485° at 10,030 m., near the bottom.

From this new material the author has calculated the stability-coefficient 10^8 E from 3500 m. to the bottom, by using the tables of Hesselberg and Sverdrup and supposing a constant salinity of 34.68 ‰. The following table shows the results.

D.	10^8 E.
3500— 4000	+ 1.2
4000— 4500	+ 0.8
4500— 5500	— 0.3
5500— 6500	+ 0.5
6500— 7500	+ 0.7
7500— 8500	+ 0.2
8500—10030	+ 0.8

[1]) Wüst finds only small values to which he does not attach much weight.

Von Schubert concludes from these data that all layers between 3500 m. and the bottom — with the exception of those between 4500 m. and 5500 m. — are practically (*praktisch*) in indifferent equilibrium. When the exception between 3500 m. and 4500 m. is mentioned, the expression "stable" would be preferred by the reviewer. If a value of E = + 1.2 is regarded as representing "practically" indifferent conditions, the same holds good also for E = — 0.3.

The author deals further with the opinions of A. Defant and W. Schmidt concerning the circulation of the water in deeper layers of partly enclosed basins, in relation to the vertical temperature gradient below the minimum level.

An investigation of the whole corrected material of the Snellius Expedition in a manner more thorough than was possible for preliminary reports of the expedition may throw more light on these difficult questions.

v. Riel.

S. Kokubo and **T. Tamura.** A Quantitative Investigation of the Plankton of Aomori Bay, as Studied Comparatively by Pump and Net Collection. Science Repts. of the Imperial Univ. of Tôhoku. Ser. IV, Biol., Vol. VI, No. 3, pp. 491—531. Sendai, 1931.

The authors studied the seasonal numerical fluctuations and the vertical distribution of the plankton in this relatively shallow bay by means of twelve sets of observations extending over the period Aug. 26, 1930, to Apr. 14, 1931. Collection was by pump and by vertically hauled townets, which were of two kinds (both of No. 25 Müllergaze), the Hensen type and a simpler one in which the mouth was not reduced as in the Hensen. It was assumed that the catches by the pump method were truly representative of the amount of plankton present per unit volume of sea water and these figures were utilised to obtain a measure of the efficiency of the two types of nets. The results obtained in this connexion were of considerable importance. They may be briefly summarised as follows: — In the net of the ordinary type the ratio of the area of mouth to the filtration area was 1:17.7; in the Hensen 1:56. In both cases, however, the efficiency of the net was found to be low, the mean coefficients of filtration for a 30 metre tow being 7.85 (with a probable error of ± 1.46) and 6.26 (with a probable error of ± 1.38) respectively. The coefficients of filtration for both nets shewed a tendency to vary proportionally to the quantity of plankton captured and for the same reason was also proportional to the distance the net was hauled. Selected portions of Table b, p. 520, may be cited to give an idea of the magnitude of the fluctuation.

Observation XII. Hensen Net. April 14. 1931.

Distance of Haul	Actual catch	Filtration coefficient	Distance of Haul	Actual catch	Filtration coefficient
4—0 m.	9.0 cc.	1.57	20—0 m.	12.7 cc.	6.70
8—0 -	14.0 -	2.52	24—0 -	15.6 -	6.95
12—0 -	15.0 -	3.24	26—0 -	17.0 -	7.06
16—0 -	16.0 -	4.29	30—0 -	15.0 -	9.67

These facts led the authors to conclude, p. 530, that "when the nets . . . are towed 30 meters (*sic*) vertically, the filtration coefficients are not only very large but also fluctuate so much as to make impossible the use of these nets for quantitative purposes." They state, too, that in order to obtain an exact result under conditions when the plankton production is in the region of 200 cc. per cubic metre either the ratio of mouth to filtration area should be about 1:300, or that hauls should not exceed 5 metres in length. The variation in efficiency of nets due to clogging has been stressed by other workers but it is unusual to find much importance attached to this source of error. The authors are therefore to be congratulated in boldly stating this important fact anew.

The bulk of the plankton taken in both pump and net collections consisted of such Diatoms as *Chaetoceras spp.*, *Rhizosolenia spp.*, *Thalassiothrix spp.*, etc. The composition, of course, varied with the season of the year. There were well-marked autumn and spring maxima in September and March. The amount of plankton per unit volume was expressed throughout the paper as a volume obtained by allowing the catches to settle in a graduated cylinder. In this connexion the authors state, p. 499, "Looking through the specimens collected from different depths it is remarkable that the specimens taken from 2—4 metres showed a voluminous cottony condition while that of 15 metres gave dense deposition, the two differing markedly from each other. On examining these under the microscope it was found that the cottony sediment is composed of *Chaetoceras* and the dense deposit is mainly composed of such spineless diatoms as *Rhizosolenia*, *Biddulphia* and *Coscinodiscus*." Again on p. 511, there is the comment "Due to scantiness of *Chaetoceras*, the specimen deposited densely." It is highly probable that on this account the amounts of plankton in those cases where the specimen did not pack tightly have tended to be overestimated. Moreover since *Chaetoceras spp.* tended on the whole to favour the upper waters the apparently well-marked abundance of plankton in this layer, which was so obvious in the autumn, may have been somewhat exaggerated.

Using the pump, and filtering 30 litres of water each time from, usually, the following depths 0, 2, 4, 6, 8, 10, 15, 20, 25, and 30 metres the authors were enabled to trace changes in the vertical distribution of the plankton (as a whole) over the period August to April. The results are striking and may be given in the authors' own words, p. 522. ". . . the first two observations (Aug. Sept.) show clearly that the abundance of plankton is highest in the upper layer and decreases by degrees with depth. In three subsequent observations (Sept.—Oct.), however, the distribution tended to become somewhat homogeneous from the surface to the lower layer. And in the succeeding four observations (Oct. —Jan.) the distribution became really homogeneous throughout the whole layer." Vertical distribution was not studied in February. "But the results of the last two observations (March—Apr.) roughly show a tendency that the lower stratum is more concentrated than the upper stratum."

It is unfortunate that observations were not continued throughout a year and particularly into the early summer when the amount of illumination would be at its maximum.

As regards diurnal changes the authors state in their summary, p. 530,

"As to whether the phytoplankton exhibits any vertical migration due to the change of intensity of light the present data are not determining. But it can possibly be said that such migration is improbable diurnally, but probable seasonally." Since on one occasion only were changes in vertical distribution at different times of day sought for (Oct. 10, 1930) and since here only two series of collections were made, one in the forenoon (8.40—9.30 a. m.) and the other in the afternoon (2.30—3.30 p. m.) this statement is somewhat misleading. The pump method, however, would seem to be particularly well suited to the study of diurnal changes in the vertical distribution since the time required to sample 16 different levels was only 70 minutes (p. 520) and it is to be hoped that perhaps the authors will continue their studies with particular reference to this question.

A. C. G.

S. M. Marshall and **A. P. Orr.** A Study of the Spring Diatom Increase in Loch Striven. Journ. Mar. Biol. Assoc. N. S., Vol. XVI, No. 3, Plymouth, 1930.

Im Loch Striven (Clyde Sea Area, Schottland) wurden 1926 1mal wöchentlich und 1927 und 1928 mit nur wenigen Tagen Zwischenraum Untersuchungen über den Verlauf der Frühjahrs-Diatomeen-Wucherung angestellt. Das Plankton bestand fast ausschliesslich aus *Skeletonema costatum*, welches fast eine Reinkultur in See bildete.

1926 und 1927 begann die Wucherung (1927 schon vor 8. März) an der Oberfläche und setzte sich nach der Tiefe zu fort. Nach etwa 3 Wochen nahm die Zahl der Diatomeen schnell ab, und die Wucherung war beendet. Während der Wucherung vermehrte sich der Gehalt des Wassers an Sauerstoff und pH, während der Phosphat-Gehalt sank. Jedoch hörte die Vermehrung der Diatomeen auf, bevor alles Phosphat verbraucht war, es wird angenommen, dass in diesem Falle ein anderer nicht untersuchter Nährstoff aufgezehrt war. 1928 war der Verlauf der Wucherung unregelmässiger, da durch thermisch bedingte vertikale Wasserbewegungen die Diatomeen-Bestände verschiedener Schichten zeitweise durchmischt wurden. Solche Mischungen können auch durch Wind herbeigeführt werden. In diesem Jahre wurde am 6. April ein neuer Zellen-Typ (grössere und längere Zellen) gefunden, der nach einigen Tagen wieder verschwand.

Durch Versenken von Diatomeen-Kulturen in das Wasser wurde die Intensität der Assimilation (Sauerstoff-Produktion) in verschiedenen Tiefen geprüft. Wenn die Diatomeen an der Oberfläche zahlreich sind, ist die Assimilation schon in geringer Tiefe infolge Beschattung herabgesetzt. Durch weitere Versuche wurde festgestellt, dass eine Beziehung besteht zwischen der durch Permanganat oxydierbaren organischen Substanz und der Menge der Diatomeen. Der Gehalt des Mediums an organischer Substanz nimmt zu mit der Vermehrung der Diatomeen. Der Zeitpunkt für den Beginn der Wucherung wird im Loch Striven hauptsächlich durch die Zunahme der Lichtintensität bestimmt.

Künne.

Johan T. Ruud. On the Biology of Southern Euphausiidae. Universitetets Biologiske Laboratorium. Hvalrådets Skrifter, Nr. 2. Oslo, 1932.

Der Verfasser hat als Assistent von JOHAN HJORT an einer Fangreise des Waldampfers "Vikingen" in die Weddelsee teilgenommen. Die dabei angestellten Untersuchungen bezogen sich auf die hydrographischen und biologischen Bedingungen des Zustandekommens von Walfanggebieten. Da hierbei die Nahrung der Wale von besonderer Bedeutung ist, richtete sich die Aufmerksamkeit hauptsächlich auf die Untersuchung des "Krill", der Euphausiiden, die sowohl durch Planktonfänge wie auch aus Walmägen gewonnen wurden.

Hydrographisch sind in der Weddelsee zu unterscheiden 1) antarktisches Oberflächenwasser, kalt, schwach salzhaltig, sauerstoffreich, bis 150—200 m in die Tiefe gehend, 2) die antarktische Zwischenschicht atlantischen Ursprungs, wärmer, salzreicher, sauerstoffärmer, bis etwa 1500 m hinab, 3) antarktisches Bodenwasser mit mittleren Verhältnissen von Temperatur, Salzgehalt und Sauerstoffgehalt.

Da die Nahrung der Wale fast ausschliesslich aus *Euphausia superba* besteht, wurde diese besonders eingehend studiert. Sie ist eine rein antarktische Art der obersten Wasserschicht. Obwohl die Beobachtungen sich nur auf die Zeit von Oktober bis Februar erstreckten, war es doch möglich, den ganzen Lebenskreislauf der Art zu rekonstruieren. Die inneren Geschlechtsorgane reiften während dieser Monate. Die Eiablage fand in der ersten Januarhälfte statt, und zwar dicht bei oder unter dem Treibeise. Es traten im Plankton Eier, danach heranwachsende Larven auf. Während der gleichen Monate fanden sich in den Walmägen zwei Grössengruppen von *E. s.*, doch näherte sich die kleinere im Laufe der Zeit heranwachsend der grösseren. Letztere war immer geschlechtsreif, erstere unreif. Nach dem allen ist folgender Entwicklungsgang anzunehmen: Die im Januar geborenen Tiere haben im Februar 8—10 mm, im Oktober 16 mm, im nächsten Februar über 40 mm Länge (Gruppe I). Im zweiten Herbst sind sie 42 60 mm lang (Gruppe II) und laichen im Januar. Die Geschlechtsreife wird also nach zwei Jahren erreicht. Gruppe I heisst bei den Walfängern Blauwalkrill, Gruppe II Finwalkrill. Ausser *E. s.* kommen noch drei Arten von Euphausiiden vor, von denen *Thysanoessa macrura* in den Planktonfängen unter allen die häufigste Art ist, während sie in den Walmägen nie gefunden wurde. Ihre Lebensweise ähnelt augenscheinlich derjenigen von *E. s.*

Erfahrungsgemäss wandern Finwale und Blauwale im Frühling und Sommer in ihre Ernährungsgebiete in höheren Breiten, im Herbst in entgegengesetzter Richtung. Walgründe befinden sich teils in den Ernährungsgebieten, teils in den Fortpflanzungsgebieten, doch sind erstere ergiebiger. Es lässt sich gut nachweisen, dass Hauptwalgebiete mit Gebieten besonderer *Konzentration des Zooplanktons* zusammenfallen. Bei More in Norwegen erscheinen im Anfang des Jahres Finwale auf Grund der Fortpflanzungsansammlungen von *Thysanoessa inermis*, im April Seiwale, welche sich von den *Calanus*massen nähren, die nach der Frühjahrswucherung des Phytoplanktons am Aussenrande der Küstenbank entstehen, schliesslich im Mai bis August ebenfalls dort wieder Finwale, welche von der dann laichenden *Meganyctiphanes norvegica* leben. Hauptsächlich in Konvergenz- und Stau-

wassergebieten zwischen dem Küstenwasser und dem Golfstromwasser kommt es zu grossen Planktonansammlungen. In der Davisstrasse, bei den Faröer und Shetlandinseln, bei Finmarken, der Bäreninsel und Spitzbergen, schliesslich bei Island sind die Walgründe vorwiegend Mischungsgebiete. Von den antarktischen Gründen ist besonders der von Südgeorgien charakteristisch. Westlich der Insel entsteht bei starker Nährstoffzufuhr reiches Phytoplankton, während der darauf gegründete Krill sich im Stauwasser an der Ostseite ansammelt. Im Strömungssystem des Nordmeers ist das südlichste der drei grossen zyklonischen Systeme zugleich das Gebiet der Dögling-(Bottlenose-) Gründe, die ostgrönländische Polarfront ein alter Grönlandwalgrund. Die Sargassosee, ebenfalls ein Konvergenzgebiet, war Hauptfanggebiet für Potwale. Ein Konvergenzgebiet liegt auch im Innern der äusserst nährstoffreichen, für den südlichen Walfang — auch den bei Südgeorgien — durch ihre Planktonproduktion so wichtigen Weddelsee.

Der Wert der Arbeit liegt also einerseits in der Aufklärung des Lebenskreislaufs des Krill, anderseits darin, dass sie zeigt, welche Bedeutung für die Entstehung von Walgründen nicht sowohl die Produktion von Plankton überhaupt, als vielmehr die Konzentration von Krill durch Strömungen bestimmter Art hat. Solche Konzentration findet statt in Konvergenz-, Mischungs-, Stauwasser- und Wirbelgebieten. E. H.

E. B. Worthington. Vertical movements of fresh-water Macroplankton. Internat. Rev. d. ges. Hydrobiol. u. Hydrog. Bd. 25, Heft 5/6, pp. 394—436. Leipzig, 1931.

Two sets of experiments are considered, the one made in Lake Lucerne, the other in the Victoria Nyanza. The African observations came first in point of time, being made in September, 1927, but the Swiss results, obtained in September, 1928, have very properly been considered first. In completeness they surpass any similar experiments that have been made so far. The objects were (p. 401): — "to determine the depth to which each species migrated, the times at which each ascent and descent started and finished, and so the speed of up and down movement." In my opinion all these ends were successfully achieved.

In Lake Lucerne 17 series of stage-catches with a vertical Nansen-type closing-net were made at almost hourly intervals between 5.0 a. m. on Sept. 10th and 9.0 a. m. the following day. The lake was 106.5 metres deep, and was sampled by 7 vertical stage-catches from 105 metres to the surface. Each series took from 30—40 minutes only, in contrast to the $1^1/_2$ hours needed to complete a series of 5 horizontal hauls (Russell, 1). The results, particularly at the dawn and dusk periods, have demonstrated clearly the necessity of speedy collecting methods.

The sources of error likely to be encountered in work of this kind are discussed (pp. 402—405). The practice of giving a few quick turns to the winch at the moment when the "messenger" strikes in order to compensate for the drop of the net is one worthy of imitation. In L. Lucerne inequalities in the horizontal distribution of the plankton (the bugbear in all work of this kind) were not apparent. In the Victoria Nyanza, however, swarming was evident in certain species.

A well-marked diurnal migration was undertaken by nearly every species, up by night and down by day. The extent of the migration, though not the direction, nor indeed the times of commencement, varied with different species, and particularly with adults and young of the same species. WORTHINGTON suggests therefrom that "the same factors are influencing the migrations of all species alike."

Ontogenetic differences in behaviour were particularly striking in the case of *B. coregoni*, in which adults migrated scarcely at all, whilst young descended from about 7 to 55 metres between 5 and 9 a. m., returning at 6 p. m. With the exception of the adult *D. gracilis* and the young of *D. laciniatus* the histograms representing the migration are unimodal. It would be interesting to know if the bi-modality in the case of *D. gracilis* was due to a difference in the behaviour of the sexes. A further point which would seem to emerge from the figures on p. 413, and upon which WORTHINGTON does not comment, is that the Copepods, with the exception of *C. leuckarti*, do not migrate up so far as the Cladocera.

By reason of the short interval of time separating the observations, WORTHINGTON was enabled to calculate the speeds of ascent and descent in the various classes of individuals. He suggests that the descent in the case of the young of *D. longispina*, at any rate, must be brought about by the animals' active movements and not merely as a result of passive sinking. It would be of great interest to know the rate at which an individual, which has become modified to warmer water in the manner suggested by WESENBERG LUND, would sink in the relatively very cold water below the thermocline. It is, perhaps, legitimate to hazard the suggestion that the fact that the Cladocera in L. Lucerne, despite a surface temperature of 21° C, were not typical summer forms may be the outcome of their behaviour. WORTHINGTON (p. 425) contrasting the behaviour of *D. longispina* and *D. lumholzi* in the Victoria Nyanza says: — "it is significant that this species (*D. lumholzi*) which has a well developed helmet undergoes less movement than the small-helmeted *D. longispina*. It may be therefore, that future work in temperate lakes will show the large-helmeted form of *D. longispina* to undergo less movement than the small-helmeted forms." It is not quite clear what reasons have prompted this suggestion since in the Victoria Nyanza the water was not thermally stratified.

The following points demonstrated by the experiment may be quoted: — (pp. 428—429) (1) " . . . there can be no doubt that light is the most important factor, . . ."

(2) " . . . the descent is finished well before the sun attains its zenith."

(3) "The main upward movement does not start till dusk, and continues for several hours after complete darkness."

(4) "There is very little tendency to random distribution during the later hours of darkness. . . . The Lucerne plankton shows a slight tendency to descend at a uniform rate after it has attained its highest point, . . ." (this is within about $2^1/_2$ hours after dark, at 10 p. m.).

Consideration of these facts compels WORTHINGTON to disagree with RUSSELL's optimum light intensity hypothesis, (RUSSELL, 2 & 3) and to put forward an alternative as follows: — (p. 432) "The organisms may be regarded as being under the influence of two forces: (1) a negative geotro-

pism, acting persistently from below, and, when it has free play, causing them to congregate in the upper layers, and (2) a negative heliotropism, acting intermittently from above and causing those species which are susceptible to light to descend during the day." WORTHINGTON asks himself, very properly, why the organisms " . . . should prefer the upper water layers and should go to the astonishing expense of energy of swimming upward against gravity through some 50 metres of water every evening." He finds the answer to this in their feeding habits.

In view of the well-known differences in behaviour which the same species of fresh-water Crustacea may exhibit in different bodies of water, he is a bold man who will formulate an hypothesis on the results of two experiments even though they refer to such widely separated parts of the globe as Switzerland and Equatorial Africa. Observations on the behaviour of *D. longispina* in Lough Derg, for instance, suggest that WORTHINGTON's hypothesis is not of general application. In a continuation of an earlier paper on this subject by Mr. R. SOUTHERN and myself (SOUTHERN & GARDINER, 4) our results are discussed in the light of WORTHINGTON's hypothesis. — (SOUTHERN and GARDINER, 5.)

With his deductions even as applied to his own results I find myself in only partial agreement. In the first place the reason for the gradual descent taking place from about 10 p. m. until the dawn, which is shewn by almost all classes of individuals, is not clear. Strictly according to the hypothesis the animals should continue to congregate at the surface during complete darkness. A more difficult case, however, is found in the Victoria Nyanza results where adults of *D. longispina* (p. 425) "were concentrated at the surface at 6 p. m. and 9 p. m. on the first evening, but by midnight it seems that about half the individuals had vacated the upper 16 metres and had descended, for a brief period only, since nearly all were at the surface again by 3 a. m."

My main criticism, however, is directed against the reason suggested by WORHTINGTON to account for the fact that the zoo-plankton seeks the upper layers and has ingrained in it a persistent negative geotropism. Assuming for the moment, that the chief food of the filter-feeders is nannoplankton (as opposed to the "Staubfeine Detritus" of NAUMANN) surely the young will be at a grave disadvantage if they are forced to spend the greater part of an early summer's day far below this alleged area of rich feeding. I feel convinced, in the case of such a widely distributed and successful species as *D. longispina*, that if only the rays of the sun had stood between the animals and the satisfaction of their hunger they could long since have adapted themselves to overcome this menace to their existence. Admittedly HUNTSMANN (6) has shewn, under the rather stringent conditions of his experiment, that sunshine is lethal to some marine Copepods, and there is, of course, abundant evidence in the paper under review and elsewhere, that the younger individuals apparently avoid the brightly illuminated upper layers. What is not proven, however, is that when by night they rise to the upper waters it is the pangs of hunger that drive them.

Finally I must admit that I find it difficult to imagine that in *B. coregoni*, for instance, the young should be so sensitive to light, whilst at first maturity they should become completely insensitive and for this reason be enabled to remain at a fixed level.

Reasons of space alone have compelled me to restrict this review almost entirely to the Lucerne experiments. The African work constitutes an important addition to our knowledge of the vertical movements of freshwater macroplankton, not only by virtue of its completeness, but also because this is the first time the question has been studied in a tropical lake.

A. C. G.

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1) **L. A. Zenkewitsch.** A quantitative evaluation of the bottom fauna in the sea region about the Kanin peninsula. 2) **M. S. Idelson.** A preliminary quantitative evaluation of the bottom fauna of the Spitzbergen Bank. 3) **V. A. Brotzky.** Materials for the quantitative evaluation of the bottom fauna of the Storfjord (E. Spitzbergen). Berichte des Wissenschaftlichen Meeresinstituts. Bd. IV, Lief. 3. Moskau, 1930.

1) In this paper the author records the results of quantitative faunistic investigations in the region of the Kanin peninsula with the 0.1 m². Petersen bottom sampler. The area investigated lies within 68°00′ N. to 69°10′ N. Lat., and 41°00′ E. to 44°00′ E. Long. In the southern part of this region homothermic conditions prevail. After the vernal heating of the Kanin Bank the water becomes warmed through in a very short time. In its central and northern parts, however, there is a very marked stratification of the water until late autumn, the temperature of the bottom waters remaining low all the year round. Two kinds of bottom deposit are present — a muddy soil around Kanin Noss and a sandy soil elsewhere, the sands being divisible into regions of high and low productivity.

The author finds that only two animal communities are present — one in the mud and one in the sand. The chief mud inhabiting species are *Cardium ciliatum, Leda pernula, Maldane sarsi, Myriochele oculata, Rhodine gracilior* and *Phascolosoma margaritaceum.* The characteristic inhabitants of the sandy areas are *Cardium groenlandicum, Cyprina islandica, Nucula tenuis, Aricia sp., Ophelia limacina,* and *Travesia forbesi.* A typical epifauna also is present on the sand, the leading species being large sized Buccinidae, Balanus sp., and Porifera. The areas of highest productivity lie to the north and east of the region explored, while in the south few organisms are stated to occur owing to the "hardness" of the bottom.

In the latter half of the summer there is a large influx of all kinds of fishes into the region — probably a feeding migration, as the fish are always most numerous where the highest productivity of bottom animals has been found.

2) During the summer of 1925 the research steamer "Persey" explored, by means of the Petersen 0.1 m.² bottom sampler, the Spitzbergen Bank situated between Bear Island and Hope Island. From the data acquired the author states provisionally that Petersen's suggestion as to the

probable composition of the population of the comparatively shallow regions in the northern parts of the Atlantic — his "northern communities" — is roughly correct. Further, the ecological and zoogeographical analysis of the bottom fauna over the whole bank leads to the conclusion that this fauna has an arctic-boreal character as understood by HOFSTEN.

This paper is a useful preliminary contribution to a knowledge of the bottom fauna of the Spitzbergen Bank. The material so far collected, being drawn from only 20 stations in an area of over 1200 square miles, is, however, too scanty to allow of any but the most tentative deductions to be drawn from it. We hope that the author may be able soon to supply more adequate data from this interesting region.

3) By means of the 0.1 m.² Petersen bottom sampler the nature of the bottom deposit and the composition of the fauna at 18 stations in the Storfjord have been investigated. The results obtained show that in all the explored part of the fjord the soil consists uniformly of mud and stones, with a correspondingly uniform bottom fauna. The characteristic species are *Astarte borealis, A. montagui, Tellina calcarea, Nucula tenuis, Maldane sarsi, Ophiocten sericeum*, and *Strongylocentrotus droebachiensis*. More detailed analysis reveals that the general population of the fjord thus outlined can be sub-divided into two separate communities: (a) an association inhabiting the shallow areas (50—90 metres) in the inner part of the fjord and showing a high productivity — 468.30 gms. (alcohol weight) on 1 m.² — where the Lamellibranchiata predominate, and (b) an association inhabiting the deep waters of the fjord at its mouth, where the productivity is small — 126.30 gms. (alcohol weight) per 1 m.² — where the Polychaeta predominate. G. A. S.

G. H. Clark. The California Halibut. (*Paralichthys californicus*) and an Analysis of the Boat Catches. Calif. State Fish. Lab. Contrib. No. 109. Fish. Bull. No. 32. Sacramento, 1931.

It is claimed that the stock of this fish is being subjected to overfishing, the investigations upon which this claim is based are detailed, and a close time for fishing is suggested as a remedy.

After a short review of the fishing grounds, which are stated to be constantly increasing in area, entailing longer journeys for the fishing vessels, it details the methods of fishing and the various restrictions that have been imposed. It then gives a graph of the total landings by districts which indicates serious declines in most districts during practically the whole of the period 1916 to 1929. From the general material, that relating to one district (Los Angeles) has been selected for further treatment, but as these landings comprise quotas from vessels that spend very different periods in this fishery, a sample consisting of the landings of what is termed suitable boats, i. e., those that fished at least two of the six-month season is examined. It is stated that gear, size and crew per boat have remained constant during the 11 years 1919 to 1929, but there is no indication as to what proportion of the total fishing power expended this sample represents each year. This omission, whilst not affecting the conclusions drawn with regard to the catch per unit of effort, may seriously impair the value of any attempt to evaluate the trend of the total stock.

During the analysis it was found that the frequencies of catch by weight gave markedly skew distributions, and, in consequence, the usual arithmetic means were supplemented by geometric means in order to diminish the influence of the extreme high values. The median values would have given still less weight to the extreme values, and would have been more easily calculated. Various methods were used to minimise the disparities in the samples, and in the course of the examination a three-year periodicity of catch was found which, it is stated, may be due to spawning variations. The possibility of long period cycles and also migrations from the area investigated is mentioned, but notwithstanding these it is held that the yield per unit of fishing power expended has seriously declined. This, coupled with decline in total catch, in the face of rising monetary value of the fish, and the continued extension of the area fished is held to be proof of overfishing.

Since 1915, the taking of fish of less than 4 lb. has been prohibited, and in 1921 it became unlawful to have in possession over 50 lb. of undersized fish. These restrictions are held not to have been of sufficient benefit to the stock, and it is suggested that April and May, the maximum spawning months, should be closed for fishing. It is calculated that normally 26 per cent. of the total catch was secured during these months. T. E.

B. Dawes. Growth and Maintenance in the Plaice (*Pleuronectes platessa* L.) Part I. Journ. Marine Biolog. Assoc. N. S., Vol. XVII, No. 1. Plymouth, 1930. Part II. Ibid., No. 3, 1931. A Statistical Study of Growth and Maintenance in the Plaice (*Pleuronectes platessa* L.). Ibid., No. 3, 1931.

We have as yet very few *experiments* concerning the growth and maintenance in the principal food-fishes; it is therefore of utmost interest that the famous Plymouth Laboratory has undertaken these experiments, proposed by the Ministry of Agriculture and Fisheries, under the direction of Dr. E. J. Allen and Dr. E. S. Russell, and we have to congratulate Mr. Dawes on the results obtained.

The experiments have been carried out during the years 1928, 1929 and 1930, partly at Cawsand, near Plymouth, and partly at Lympstone, near Exmouth, where 2—3 year old plaice were used for the experiments. The aim of the experiments is, says Dawes, to determine the food requirements of the plaice with respect to the maintenance of life apart from growth, and to ascertain what quantity of food is available for purposes of growth, after basal requirements are satisfied, in the case of an actively feeding fish during its third season of growth.

The plaice were kept in boxes floating in suitable places near the shore; the food given to the fish was *Mytilus edulis* cut up into suitable pieces; the fish were measured and weighed fortnightly. The preliminary experiments of 1928 were revised and improved on in the following years, but it is impossible here to go further into the various details and describe the modifications of apparatus and methods employed during the three years; we may, however, mention that each fish was kept quite separate from its fellows in the later experiments. Throughout the experiments, food left over from a meal was always "weighed back" before the following meal was given. The experiments were carried out mainly in the months June—

October. All the details of weighings etc. are given in about 130 Tables and in a number of curves.

In the papers Dawes discusses the results under the following headings: Minimum requirements and maintenance; maximum requirements and growth; growth and intermediate food supplies. Further, a general discussion of the results is undertaken. An objection to the papers is that a general review of the results would have been valuable for the reader who has not time to work through the many details, so much more so as the tables etc. are not easily understood. In the following we give the main results, partly by way of examples from the experiments.

It does not appear possible to supply a fixed daily ration of food for purposes of maintenance, so that the body-weight of the fish is maintained absolutely constant. *The minimum requirements* of a plaice in the third season of growth will be seen from the following Cawsand experiment from 1930. For a *male* fish just commencing its third season of growth (length 13.1 cm., weight 21.5 gm.) an average daily ration of 0.46 gm. of Mytilus flesh was necessary for maintaining its weight to within about 0.7 gm. of constancy during the period of experiment; the maintenance ratio, i. e. the ratio of food consumed per day to average body-weight, is then about 0.022 (this value can be taken as average for a fish *commencing* the third season of growth). On the other hand, a male plaice 23.0 cm. in length and 115.0 gm. in weight was able to maintain its weight to within 4.0 gm. of constancy on an average daily ration of 1.42 gm., i. e. a maintenance ratio of 0.012 (this value can be taken as average for a fish *ending* the third season of growth). Among *females* the average daily ration was 0.43 gm.; maintenance ratio 0.022, of a female 12.2 cm. and 17.3 gm. maintaining its weight to within 4.7 gm. of constancy. Thus the maintenance requirements of male and female plaice commencing the third growth-season appear to be almost identical; among females also, as among males, the maintenance ratio decreases with size, a result obtained from all experiments; for instance, a female plaice 24.5 cm. in length and 132.0 gm. in weight was able to maintain its weight to within 4.9 gm. of constancy on an average daily ration of 1.24 gm., i. e. a maintenance ratio of only 0.009. We see then that *the value of the maintenance ratio decreases with increase in weight* of the fish, in male and female alike; and the maintenance ratio is thus not constant throughout the season of growth. Considerable variation in the value of the maintenance ratio occurs, however, in different fish during the third growth-season; and the average daily ration of food required to maintain weight constant appears to vary from period to period.

As to the *maximum requirements and growth* the following can be mentioned. The results with *maximum feeding* plaice showed that growth and efficiency (as indicated by the quantity of food required to produce 1.0 gm. increase in fish weight) vary very considerably in both males and females from one fortnight to another throughout the growth season. During certain fortnightly periods 4.2—4.8 gm. of food was required to bring about an increase in weight of 1.0 gm; more commonly 10—15 gm. or more was required (Cawsand, 1930). Maximum growth, appetite and efficiency were obtained during the same period, i. e. September—October. The males show a rather more rapid growth-rate than the females at Lympstone, while at

Cawsand in 1928 the reverse was the case. Both at Cawsand and Lympstone the growth of maximum-feeding plaice was slow during 1930 and the rate of growth irregular.

Fish supplied with daily rations of food *intermediate* in value between maximum and maintenance rations and about 1/3rd the value of the former, appear to make better use of food for purposes of growth than do fish supplied with maximum rations.

Reviewing the results briefly, we learn from the experiments that about 25 % of the total food taken during the growth season of a plaice in its third season of growth is used for maintenance, and of the remainder on the average each 5 gm. of Mytilus flesh produces 1.0 gm. increase in weight of the fish; in shorter periods about 4 gm. may suffice for such an increase.

Temperature appears to influence growth directly; there is an appreciable fall in the value of the maintenance ratio during late October and November (1929), when the temperature of the sea-water is decreasing, and the fall is synchronous with the fall in the sea-water temperature; the same was seen in mid-August, 1929, at Cawsand. It was shown at Lympstone that growth of both males and females is abrubtly retarded when the maximum temperature of the sea-water approaches 10° C; growth ceases and weight is lost when the maximum temperature falls below 10° C. At Lympstone (1930) it was shown by the experiments that there is a fall in value of the daily maintenance requirements of both male and female plaice during the coldest months of the year by about $^1/_2$—$^1/_3$ of its value in warmer months. It was further seen here that maximum feeding was completely resumed before the end of March and that it was attained in little more than a fortnight; growth commenced at once, and strikingly high efficiency was shown during the first few weeks. The higher temperature at Lympstone (1929) caused the maintenance requirements to be higher there than at Cawsand, while efficiency was slightly lower. The author says, p. 907 (Vol. XVII, No. 3), "For some reason which remains unknown, the rate of growth shown at both Cawsand and Lympstone during 1930 was much slower than that shown during 1929, degrees of growth being smaller also." On plotting out the temperatures from 1929 and 1930, as far as it is possible from the temperature curves given, it will, however, be seen that the temperature on an average is lower in 1930 than in 1929 during August—September and probably the cause of slower growth in 1930 is then partly to be found here. At any rate Mr. Dawes' work supports the supposition that the total quantity of heat absorbed by the plaice during the growth-season is of importance to the weight reached during this season.

In *the statistical study* Mr. Dawes uses the data from 1929—30 for statistical treatment, which gives more reliable generalised results. A fairly high degree of correlation between food and growth, uniform for the sexes, has been found; regression coefficients indicating the facility with which food is utilised for purposes of growth show variation with place and year, but not with sex; maintenance demands have been shown to be a little greater in male than in female; and a distinct difference between the Cawsand and Lympstone plaice has been shown, probably arising out of size differences to a large extent.

The author expresses the conviction (somewhat hastily) that the results

of the experiments make it possible for us, by a process of analogy, to "arrive at an approximate evaluation of the maintenance requirements of fully-feeding, freely-growing plaice, using methods which are more in keeping with growth experiments than others which might have been selected, e. g. determination of maintenance requirements by study of respiratory exchanges". A combination of the two methods is probably to be preferred.

The results of the experiments hold good for 2—3 year old plaice of that special area on the southern border of the whole area of distribution of the species and feeding on Mytilus flesh only; as soon, however, as we consider plaice of other races in other areas, e. g. Iceland and the Barents Sea and feeding on other material, it appears that similar experiments are necessary to get results of value for estimating the maintenance requirements of freely-growing plaice there. For instance, we have seen that growth ceases at Lympstone when the maximum temperature falls below 10° C; in some parts of the plaice area in the high North the water never or rarely reaches this temperature and yet the plaice grow fairly well. What are the maintenance requirements here and how many grams of Mytilus flesh and other food is necessary in this case to produce an increase of 1 gm. in weight? We have in the present experiments only faint hints as to the solution of this question, and we hope therefore that it will be possible in the future to perform investigations with other races of plaice also, giving information as to the importance of locality, food and temperature in the whole area of distribution.

Å. Vedel Tåning.

G. Lyman Duff. Factors Involved in the Production of Annual Zones in the Scales of the Cod. (*Gadus callarias*. Linn.). Contributions to Canadian Biology and Fisheries. N. S., Vol. IV., No. 21. Toronto, 1929.

The object of this work was to determine the relationship between the rate of growth of the cod in length, the rate of growth of the scale, and the production of the annual rings. Some 2,700 fish were examined and preliminary observations were carried out before the main work was begun. This consisted of determining the amount of dispersion of the measurements of several scales from a given area on a single fish, and, as the measurements seemed to group themselves fairly normally about a mode, it was decided that an average of ten scales taken at random would represent the length of the scale for any fish.

The growth of the cod was studied by measuring the individuals of the 1922 year-class, this being the youngest year-class in the material, and as such, made age estimation the more accurate. A curve showing the growth from August 1925 to September 1926 was produced.

By measuring the length of scale for certain increasing lengths of fish, it was found that there was a more rapid scale growth in early years than in the later years of the fish's life. The author also found that there was a variation in the rates of growth of the scale and the fish according to the time of year when the observations were made. To demonstrate this he selected fish of 50 –55 cm. throughout the period of observation and measured the scales of the fish, the result being an undulating "scale-length"

curve with maxima approximately in early spring and minima in late summer. Now, there can be no doubt that this curve does not represent the true growth of the scale, and the author has fallen into the trap by using the same length-group of fish throughout a long period.

Space does not permit one to give a full graphical description of the fallacious use of the data, but the explanation lies in the drawing of a correlation surface representing the growth of the scale against the growth of the fish, and observing that as the ellipse moves along the axis of growth, the distribution of the fish in the 50—55 cm. group is constantly changing. If all the averages for each slight movement of the ellipse along the axis of growth are plotted, an increasing value will be obtained, the maximum being reached when the year-class has grown so much that most of the fish are larger than 50—55 cm. By continuing the observations, the series of averages will begin again at the minimum position as a new year-class makes its appearance, thus producing an undulating curve.

From the counting of the number of circuli on the scales throughout the year, it was found that the zone of broad circuli was produced between March and July, while the greater part of the narrow zone was formed between August and December, and during the winter the number of circuli was practically constant. These results agree fairly well with the observations on the time of growth of the herring scale.

In the section on the rates of growth of fish and scales, the author concludes that the cod grows quickest during May, June and July, and that in January and February there is practically no growth. His conclusions regarding the rate of growth of the scale cannot be altogether true since he has corrected the growth curve of the scale for the "seasonal variation" shown above to be fallacious.

The circuli in the scales are produced at the greatest rate during September, while in January and February there is practically no production.

W. C. H.

E. Ford. 1) Growth in Length during the Transititon from Larva to Adolescent in the Pilchard and Sprat. 2) Changes in Length during the Larval Life and Metamorphosis of the Freshwater Eel (*Anguilla vulgaris* Turt). Journ. Mar. Biol. Assoc. N. S., Vol. XVII, No. 3. Plymouth, 1931.

1) In einer früheren Arbeit hat sich Ford mit der Frage nach den Veränderungen der Lage von After und Flossen zueinander und zu den Wirbeln beschäftigt. Ford hatte die Überzeugung ausgesprochen, dass gewisse Körperabschnitte, nämlich vom Hinterende des Kopfes bis zum Beginn der Rückenflosse und von der Ansatzstelle der Bauchflossen bis zum After, während der Metamorphose in ihrer Länge unverändert blieben, während andere Körperabschnitte an Länge zunähmen, dass also die Lageveränderungen durch ungleichmässiges Wachstum der verschiedenen Abschnitte hervorgerufen würden. Mit dem gleichen Problem beschäftigt sich Ford in der vorliegenden Arbeit bei der Sardine und beim Sprott. Die Methodik ist ebenso wie bei der ersten Arbeit.

Ford kommt nun auf Grund seiner Messungen und Vergleiche zu dem Ergebnis, dass im Gegensatz zum Hering, bei dem *zwei* Körperabschnitte

während der Metamorphose in ihrer Länge unverändert bleiben, beim Sprott und bei der Sardine nur *ein* Körperabschnitt die gleiche Länge während der Metamorphose behält. Bei der Sardine ist dieser Abschnitt der Abstand vom Hinterrand des Kopfes bis zum ersten Strahl der Rückenflosse, beim Sprott der Abstand von den Bauchflossen bis zum After.

Es werden noch weitere Verschiedenheiten in den Wachstumsverhältnissen bei den drei miteinander verglichenen Arten hervorgehoben, und es wird auf die Veränderungen hingewiesen, die, teilweise mit Unterschieden bei den einzelnen Arten, in den Lagebeziehungen hervorgerufen werden.

2) Diese Arbeit beschäftigt sich mit dem gleichen Problem wie die vorhergehende, und zwar in diesem Falle beim Aal. Beim Aal erfolgen während der Metamorphose ja recht erhebliche Veränderungen, deren eingehendere Untersuchung von Interesse ist. Die Messungen, Berechnungen und Überlegungen sind in ihren Ergebnissen, wie der Verfasser selbst betont, vielfach noch etwas unsicher, aber sie sind deshalb doch von grundlegender Bedeutung und geben Anregung und Basis für weitere Untersuchungen dieser Art. Aus den Berechnungen, die hier im Einzelnen nicht näher erläutert werden können, wird der Schluss gezogen, dass während des larvalen Wachstums der Zuwachs des Schwanzabschnittes gleichmässig 3,3 mm. auf je 10 mm. Zuwachs der Gesamtlänge beträgt. Beim Wachstum zeigt sich ein Vorrücken des Afters, aber dieser ändert nicht seine Lage zu einem bestimmten Muskelsegment. Es muss deshalb das Längenwachstum in der Linie der Wirbelsäule gleich dem in der Ventrallinie sein. Der Beginn der Rückenflosse behält seine konstante relative Lage zum After bei. Es wird dabei betont, dass die Rückenflosse ihre volle Strahlenzahl bereits auf einem frühen Leptocephalus-Stadium besitzt. Daraus wird die Schlussfolgerung gezogen, dass beim Leptocephalus das gesamte Längenwachstum ungleichmässig ist, dass es nämlich postanal grösser ist als präanal.

Ford beschäftigt sich dann mit den Längenveränderungen während der Metamorphose. Den Ausgangspunkt bildet die Feststellung von Johs. Schmidt, dass die zu den Flossen laufenden Nerven von vornherein von den Myomeren ausgehen, über denen die betreffenden Strahlen in ihrer endgültigen Stellung stehen werden. Es verlaufen also die Nerven beim Leptocephalus zunächst schräg weit nach hinten. Es ergibt sich, dass die Längenveränderungen der Abschnitte in der Rücken- und Bauchlinie während der Metamorphose anders sind als während des Leptocephalus-Wachstums. Während der Metamorphose nehmen einige Körperabschnitte auf Kosten anderer schnell an Länge zu, sodass die nach vorn gerichtete Wanderung der Rückenflosse und des Afters nicht relativ, sondern absolut ist. Und während dieser Wanderung verändern der erste Strahl der Rückenflosse und der After ihre Lage zu den Muskelsegmenten.

Weiter beschäftigt sich dann Ford mit der biologischen Bedeutung der Ergebnisse. Als Ursache der Vorwärtswanderung der Flossen wird ein starkes Wachstum des Gewebes zwischen den Flossenstrahlen angenommen. Dann wird die Frage aufgeworfen, was die primitivere Form ist, ein weiter hinten oder ein weiter vorn liegender After. Der Leptocephalus wird als eine spezialisierte Larvenform angesehen, und zwar sind die Larven, deren After weiter hinten liegt, mehr spezialisiert als andere. Es wird darauf hin-

gewiesen, dass in Bezug auf die Lage des Afters die verschiedenen Aalarten sich in ihrer erwachsenen Form mehr gleichen als im Leptocephalus-Stadium. Der Grad der Spezialisierung eines Leptocephalus kann nach der Afterverlegung während der Metamorphose eingeschätzt werden. Es wird weiter darauf hingewiesen, dass Aale, die weit ab von der Küste laichen, spezialisierte Leptocephalen haben, während bei den nahe der Küste laichenden das Gegenteil der Fall ist.

Zum Schluss wird noch ein Vergleich zwischen Anguilla und Clupea angestellt. In den Wachstumsveränderungen sind bei beiden Gattungen gewisse Ähnlichkeiten, aber auf der anderen Seite auch wieder Abweichungen vorhanden. Die Ähnlichkeiten liegen in der nach vorn gerichteten Wanderung des Afters während der Metamorphose. Abweichend dagegen ist, dass beim Aal während des Wachstums der Larve After und Flossen ihre relative Lage zu den Myomeren nicht verändern, obwohl das Wachstum von Rumpf und Schwanz ungleichmässig ist. Bei Clupea dagegen verändern After und Flossen schon während des larvalen Wachstums ständig ihre Lage zu den Muskelsegmenten.

Es wird dann noch die Frage aufgeworfen, wie sich bei Clupea die Spinalnerven zu den Flossenstrahlen verhalten. Eine genaue Untersuchung hierüber ist noch nicht angestellt, es werden vielmehr nur die beiden Möglichkeiten erörtert, entweder dass die Nerven im rechten Winkel und gerade zu den Flossenstrahlen in ihrer ursprünglichen Lage verlaufen und später, nach der Wanderung, schräge, oder aber dass die Nerven zunächst einen schrägen Verlauf zeigen und bei der endgültigen Lage der Flossen einen geraden.

Hat auch bei diesen Untersuchungen, wie Ford selbst betont, das Eine und das Andere noch hypothetischen Charakter, so verdienen sie doch höchste Beachtung. Sie sind vom entwicklungsgeschichtlichen Standpunkt sehr interessant und geben manche Anregung zu weiteren ähnlichen Untersuchungen. Schnakenbeck.

C. F. Hickling. The Structure of the Otolith of the Hake. Quart. Journal Microscop. Science, Vol. 74, Part IV. London, 1931.

Seit den Untersuchungen Immermanns über die Struktur des Schollenotolithen sind eingehende Veröffentlichungen über den Bau von Otolithen nicht mehr erschienen. Umso dankenswerter ist die vorliegende Arbeit, die sich mit dem mikroskopischen Aufbau des Otolithen vom Seehecht (*Merlucius merluccius* L.) befasst. Der Autor geht dabei zunächst ohne Rücksicht auf die Möglichkeit der Altersbestimmung vor, kommt aber schliesslich auch hinsichtlich dieser Frage zu wertvollen Ergebnissen.

Nach Beschreibung der äusseren Form der Sagitta (und nur um diese handelt es sich hier) gibt der Autor ihre mikroskopische Analyse. Dabei erwies sich als besonders geeignet zum Entkalken die Fol'sche Flüssigkeit, zum Färben Saffranin und zum Aufhellen Pyridin.

An jedem Otolithen kann man zwei verschiedene Komponenten unterscheiden, eine organische und eine anorganische. Die wichtigere organische Komponente ist eine Umbildung des gelatinösen Bindegewebes im Sacculus. Sie besteht aus konzentrischen Lamellen, von denen zwei Formen, dickere

und dünnere, vorhanden sind. Die Lamellen sind in ziemlich regelmässigen Abständen von 2 μ angeordnet; die dicksten sind ungefähr 1.5 μ stark. Verbunden werden sie durch kräftige Radialfasern, die vom Zentrum des Otolithen zu seiner Peripherie ohne Unterbrechung durch die konzentrischen Lamellen laufen. Bei stärkerer Vergrösserung lösen sich die Lamellen in Reihen einzelner Punkte auf, da auch sie aus Fasern bestehen, die senkrecht zu den Radialfasern angeordnet sind.

In das so gebildete Maschennetz der organischen Grundsubstanz ist die anorganische Komponente des Otolithen in Form sehr schmaler, scharf zugespitzter Nadeln aus kohlensaurem Kalk, die bei einer Länge von 40 μ weniger als 1 μ dick sind, eingelagert. Sie laufen in derselben Richtung wie die Radialfasern und gehen, ohne durch die konzentrischen Lamellen unterbrochen zu werden, durch diese hindurch.

In diesem Punkte weicht der Autor wesentlich von der Anschauung Immermanns ab. Ebenso widerspricht er dessen Meinung, wonach die für die Altersbestimmung benutzten transparenten und opaken Jahresringe durch den anorganischen Anteil des Otolithen, die Kalknadeln, hervorgerufen werden. Er weist nach, dass, wenn man die Versuche Immermanns wiederholt und die Otolithen des Seehechts entkalkt, oder sie mit starker Natronlauge behandelt, oder sie ausglüht, das Kalkskelett die Jahresringe nicht mehr zeigt, wohl aber die organische Fasersubstanz. Er zeigt, dass die dünnen und dicken Lamellen in Gruppen angeordnet sind, und dass, wenn eine Region dünner Lamellen von einer Folge dicker Lamellen überlagert wird, eine Einsenkung ensteht, sodass schliesslich Furchen auf der Oberfläche des Otolithen den transparenten Zonen korrespondieren.

Die Ergebnisse der sorgfältigen Untersuchungen Hicklings können durchaus acceptiert werden. Doch sei zur Vorsicht gemahnt, die Befunde beim Seehecht ohne weiteres auf die Otolithen anderer Fische zu übertragen. Der Autor macht darauf aufmerksam, dass lange Zeit getrocknete Seehechtotolithen nie wieder vollständig aufgehellt werden können, wohl aber die der Scholle. Wenn er diesen Umstand mit der geringen Dicke des Schollenotolithen erklärt, so dürfte das nicht ganz zutreffen, da die grossen und dicken Otolithen anderer Fische nach dem Trocknen in Flüssigkeit ebenfalls wieder völlig transparent werden. Vielmehr kann das verschiedene Verhalten der Otolithen beider Fische als Hinweis auf bedeutungsvolle Unterschiede ihres inneren Baues gedeutet werden. Es wäre daher zu begrüssen, entschlösse sich der Autor, seine Untersuchungen auch auf die Otolithen anderer wichtiger Nutzfische, wie Scholle, Hering und Schellfisch, auszudehnen. H. L.

A. C. Johansen. The Sprat (*Clupea sprattus* L.) in the Limfjord. Rep. Dan. Biol. Stat. Vol. XXXVI, pp. 57—67. Copenhagen, 1930.

In past years sprats were not separated from young herring in the Limfjord catches, but recently this has been done, as the price obtained for sprats is much higher than that for herring. Statistics have been collected from 1919 onwards and show a catch of sprats varying from 26 tons in 1921 to the considerable figure of 819 tons in 1927 within this restricted and landlocked area, the most productive region of which appears to be the central portion, while the eastern end is of no importance. The years 1925

—1929 were the most productive, but no connection between abundance of sprats and of herring can be detected. 70 % of these sprats are exported to Germany and some to Norway and Sweden; the rest are consumed in Denmark, although no canning industry exists.

The fishing season lasts from October to May and is most intense from November to February, but sprats are present in the Limfjord even when there is no fishing (June—September). When the water becomes cold the sprats migrate to the deeper, warmer parts of the fjord. They shoal together for spawning in spring, but it is not clear from the text whether at other times the sprats are scattered or form feeding shoals. Spawning occurs from April to July and sprat eggs are commonest in the central part of the fjord where the fishing also is most productive, the maximum number observed (per sq. m. of surface) being 291 (1st—6th May 1930), most of which were in the germinal disc stage. Ripe and nearly spent sprats were found at Hvalpsund on $^{23}/_{6}$ 30.

Four samples of fish, taken in June, August and September 1930 and one in January 1916 (a total of some 560 fish), were measured and in some cases scaled for age-determination. The 0-group appears to range from 2 to 8 cm. in length with a mode at about 3 cm., while the I-group ranges from 7.5 to 11 or 12 cm. with a mode at about 9 cm., and the II-group varies from 9.5 to 12 cm. with a mode at about 11 cm.

Some fish had no trace of a winter ring when 7.5—8 cm. in length (August 1930) and even when 10—11 cm. long (January 1916), probably because they had failed to form scales before the onset of their first winter. Where the spawning extends beyond July this may cause serious errors in age-determination, which is additionally hindered by ambiguous and possibly false (secondary) rings.

Johansen concludes that the Limfjord sprat is a special race as its mean vertebral number (46.95—47.02) is considerably lower than the lowest figure recorded by Bjerkan in North Sea and Skagerak fish (i. e. 47.625 at Lowestoft).

This paper gives a good brief account of an interesting sprat population in enclosed waters, which, if it could be more thoroughly investigated, might well provide clues to the behaviour of sprats in the open sea, particularly at that time (March to October) when they desert the coast as ripe fish and are caught but rarely by fishing vessels. J. A. R.

R. E. Savage. The Relation between the Feeding of the Herring off the East Coast of England and the Plankton of the Surrounding Waters. Ministry of Agriculture and Fisheries. Fishery Investigations, Series II. Vol. XII. No. 3, 1931. London 1931.

The present report is a comprehensive work on the relation between the feeding of the herring and the plankton off the east coast of England and is — together with A. C. Hardy's paper (1924) — an important contribution to the knowledge of the food of the herring in the western part of the North Sea.

Altogether 13,923 stomachs of herring and 956 plankton samples were collected and examined. The large collection of stomachs was obtained from the Lowestoft spring and autumn fishery, the Shields summer fishery and

the Yorkshire coast fishery, mostly in 1926, but several hundred stomachs collected in the spring of 1929 are also included.

With regard to the Lowestoft spring fishery, the very interesting fact was substantiated that while *Ammodytes* was the principal species in the food in 1926 as in 1922—23 (HARDY), it was practically absent from the stomach contents in 1929 and was replaced by copepods. In the Shields area, which is the most important feeding ground off the east coast of England, the feeding activity gradually diminished from June to August, with a secondary wave of feeding during September and October. This fact is demonstrated by a correspondence between the results of the following three working methods: 1) the volume of food, 2) the percentage of herring feeding and 3) the total number of organisms per 100 feeding herring. The principal organisms in the food were copepods, especially *Calanus finmarchicus*, but *Oikopleura*, *Limacina*, *Sagitta* and larval decapods were also occasionally abundant in the food. A correlation is found between the number of organisms in the food and the landings of herring in 1926 and in 1922—23. In the former year there were three times as many food organisms in the stomach contents as in 1922—23, and the landings were nearly twice as large. As a general result it is found that there is a good relation between the abundance of planktonic food and the quantity and quality of the herring, and, further, that the herring feeds on those species which are in abundance in the plankton at the time. In regard to the question as to whether the herring feed by selection, the author is of the opinion that the herring only select the food by a definite act of capture when there is an abundance of larger organisms such as schizopods and postlarval sandeels in the plankton; at other times, there is probably what he calls "mass" selection, the herring feeding discriminately on masses of the smaller organisms. A very important point with regard to the biology of the herring is the fact that the maturity is retarded when the food supply is poor. Possibly a lack of food not only retards but even prevents maturation of the gonads. In connection with this result the author suggests that, when the food supply is poor, herring which should spawn in winter may not do so until the following spring.

In the last part of the paper an estimate is given of the quantity of planktonic food required by the herring. An interesting calculation is made of the quantity of food required for one "meal" (of less than a quarter of the stomach capacity) for a million herring at different periods of the feeding season. It was estimated that during the height of the feeding season in 1926 this number of herring contained 305 kilogrammes of food for the ten-day period ending 8th June, and 149, 137 and 104 kilogrammes for the succeeding ten-day periods; put another way, one English ton of plankton provided one meal for a shoal of 3.3 million herring during the first period of June, and 6.8, 7.4 and 9.8 millions for the following three periods. From these calculations it follows that, to provide one "meal" for all the herring landed from English East Coast ports during 1926, about 300 tons of plankton would be required. It seems clear that, to obtain such a large quantity of food regularly, the feeding shoals of herring have to explore a very wide area of the sea. The calculations are naturally quite rough, as we still feel the want of more exact and extensive experiments on the feeding habits

of the herring. We do not yet know whether the herring feeds continuously, or in waves, or at certain times of the day and night. A few experiments have been made, giving no definite solution, and it is therefore to be hoped that special investigations regarding this question may be carried out in the near future.

The paper is very fully documented, containing *inter alia* some useful observations on the vertical distribution of various species of plankton animals, and gives a clear, concise and suggestive account of the investigations carried out. P. JESPERSEN.

B. Storrow and **D. Cowan.** Herring Investigations. 1. Herring Shoals, by B. STORROW. 2. Size, by D. COWAN, Dove Mar. Lab. Rep. for Year ending June 30th 1930. N. S. XIX. Newcastle-on-Tyne, 1931.

In these two papers Mr. STORROW and Mrs. COWAN furnish their annual report on the Herring samples examined at Cullercoats during the latter half of 1929 and the first half of 1930. The samples numbered 17 and comprised nearly three thousand fish. As usual they cover a large area, from Yarmouth to the Orkneys and the Donegal coast.

The analysis of winter rings shows that, as in the previous year, the year group of 1925, by the author's notation, with four winter rings in 1929 and five in 1930, was almost universally predominant, with the 1924 year group a good second, while the 1922 year group, also initially a good one, occurred in large numbers in two samples, one from Yarmouth in December and one in January from the Firth of Forth.

Mr. STORROW still apparently adheres to his belief that the variations in a fishery from year to year are due primarily to widespread hydrographic changes, and only very grudgingly admits the possibility of a poor fishery being due to the numerical weakness of one or more year classes. He suggests that the fish are in existence but that, by reason of changes in the strength of the influx of the Atlantic current, they have not joined the usual spawning or feeding shoals. This theory involves the assumption, in the present case, that in 1927 the conditions were such as to attract 2 winter ringed fish, or, as Mr. STORROW puts it in his report on that year, there was an impetus to change which brought large numbers of young fish to certain fishing grounds, and that in 1928 3 w. r. fish, in 1929 4 w. r. fish, and in 1930 5 w. r. fish were in succession brought to the fishing grounds by successive alterations in the hydrographic conditions; a series of coincidences in the units of change which it is difficult to accept, though it cannot be denied that hydrographic changes may have a superimposed effect on the migratory movements of shoals of predetermined composition.

An interesting point brought out in this paper is the high proportion, in the 1929—30 samples, of fish with "marked" scales, i. e., with an outer growth zone wider than the preceding inner one. Normally we should expect a small proportion of such fish in any large sample, but the large numbers occurring in several samples seem to need explanation. Mr. STORROW's suggestion that the "marked" fish had temporarily spent some time in an area of rich feeding is a reasonable explanation but not necessarily a complete one, and such areas undoubtedly exist; the growth measurements

which he gives indicate that the marked fish from both Yarmouth and Lerwick had grown for a time at a rate equivalent to that of Atlantic, e. g., North Donegal, herrings. He does not point out, however, that in most cases the inner narrow zone, or pair of zones, represents a rate of growth well below the average for the rest of the sample, and an area of corresponding low growth must be sought to make the explanation complete. It is to be hoped that Mr. STORROW will follow up this question in all its bearings.

G. P. F.

A. Krogh. Dissolved Substances as Food of Aquatic Organisms. Biol. Reviews, Cambs. Phil. Soc. Vol. VI, No. 4, pp. 412—442. Cambridge, 1931.

Since their first appearance in the years between 1907 and 1909, the theories of PÜTTER on the importance — according to their author, indispensable character — of dissolved organic matter in the nutrition of aquatic and marine animals have perplexed and divided marine biologists and given rise to disputes only exceeded by those occasioned by the theory of the inheritance of acquired characters. But here the resemblance ends, for the theory of PÜTTER is at least capable of definite experimental verification. The difficulty has been that its adherents have been prepared to accept PÜTTER's experiments and the conclusions he has drawn from them, whereas its opponents have never been prepared to go to the great expense of labour and time, which the experimental refutation of the theory would involve, merely to obtain negative results.

Nevertheless there has been gradually accumulating a body of evidence entirely in opposition to PÜTTER's views. This has recently received important additions by the work of Professor AUGUST KROGH and his co-workers, but no less important than his original contributions is the subject of this review, in which Professor KROGH subjects the experiments and conclusions of PÜTTER to a penetrating analysis.

At the time of their original appearance the views of PÜTTER were supported by the apparent absence of sufficient phytoplankton to supply the nutritional needs of the animals. Since a certain amount of organic matter must pass into solution whenever any animal or plant dies, it seemed not an unreasonable assumption that the balance of the needs of the living animal were made up by this agency. PÜTTER deserves credit for realizing this, but it is certainly unfortunate that he did not delay the investigations he immediately set on foot to test the truth of this assumption. The discovery by LOHMANN in 1909 of the nannoplankton, which had hitherto been overlooked because it passed through the meshes of the finest silk tow-nets, altered the whole position. Further work in this field has only emphasized the abundance, and all-importance as food for many aquatic organisms, of the nannoplankton, ALLEN in 1919 demonstrating by culture methods that probably over a million organisms may occur in one litre of sea-water.

Having made his assumption, however, PÜTTER proceeded to prove his case and he has maintained it ever since in spite of all opposition. Although, following the criticisms of HENZE and RABEN, he reduced his original inordinately high figures for the amount of organic matter in solution

in the sea, the figures in his more recent papers are shown by Professor KROGH to be based largely on unwarranted assumptions and faulty experimental technique. In his contention that organic matter is given off by algae during life, PÜTTER has recently had the weighty support of GAARDER and GRAN — though their figures are much lower than his — but here again the work of KROGH and LANGE indicates that at least 90 % of the organic matter formed by algae is stored within them, while the actual increase in organic matter found in the water after an algal culture has been allowed to flourish in it may originate entirely from dead algae. A very important point established by KROGH is that of the admittedly relatively high content of organic matter present — at least 10 mg. per litre with a combustion value of 40 calories in most fresh waters, with probably very similar figures for sea-water —, the greater part consists of waste products, difficult (e. g. pentosans) or impossible of assimilation by animals and in some cases even resisting the attack of bacteria.

PÜTTER's experiments on the alleged power of a variety of invertebrates and of fishes to absorb dissolved organic matter are examined by KROGH with the same searching criticism. PÜTTER's work on fishes was disproved by LIPSCHÜTZ working in his own laboratory, his work on Ascidians and Actinians is shown by KROGH to be invalidated by errors inherent in the permanganate titration method, while his work on the absorption by Copepods of glucose is similarly invalidated by PÜTTER's failure to remove bacteria from the water. In his consideration of work by others on this subject KROGH admits, rightly in our opinion, the conclusions of PETERS on the ability of the infusorian, *Colpidium colpoda*, to live in water containing dissolved organic matter but no particulate food, and those of KŘÍŽENECKÝ and co-workers and others on the ability of tadpoles to absorb small quantities of dissolved organic matter when the solutions are of relatively high concentration. These conditions were too abnormal to lend support to PÜTTER's theory, but in other experiments KŘÍŽENECKÝ did find that tadpoles grew in water with small amounts of peptone and saccharose or of bioklein. Even here, however, some series gave discrepant results which throw doubt on the interpretation of all. KROGH's own work on absorption of glucose and other organic matter by freshwater mussels and fishes, *Daphnia* and tadpoles failed to show any significant absorption of dissolved matter except under somewhat abnormal conditions.

PÜTTER has claimed that in aquatic animals generally absorption occurs through the entire surface of the body (even in Arthropods!) and especially the gills. There is far more to be said in criticism of this than is contained in KROGH's review. The recent developments in knowledge concerning the feeding mechanisms and digestive physiology of marine invertebrates have revealed their remarkable degree alike of efficiency and specialization (see reviews by YONGE (1928) "Feeding Mechanisms in Invertebrates", Biol. Reviews, III, p. 21, and (1931) "Digestive Processes in Marine Invertebrates and Fishes", this Journal, VI, p. 175). It can be taken as axiomatic that animals do not evolve such highly efficient organs if they are not of primary importance, whereas PÜTTER would have us believe they are of minor importance. There is no valid evidence, as KROGH points out, that the skin or gills of any animal absorb. Where dissolved organic matter

is removed from the water, e. g. by Lamellibranchs and Asteroids, this ceases when the mouth is plugged. In the many experiments we have personally conducted on the absorption of iron saccharate by Coelenterates, Molluscs, Crustacea and Tunicates, absorption was never observed except in regions of the gut specialized for that purpose. Nothing can be based on the sparseness of the intestinal contents in any animal. Carnivores, — Coelenterates at one extreme to fishes at the other — digest with remarkable speed, while the flagellates and peridinians secured by the ciliary feeding mechanisms of the Molluscs or the setous mechanisms of the lower Crustacea are unrecognizable before they have even reached the stomach. The absence of food in the gut of *Rhizostoma*, especially mentioned by Pütter, is the result of the extra-intestinal digestion of this animal, only the fluid products of digestion being sucked in through the fine openings in the manubrium.

In his most able review Professor Krogh has established, in our opinion, the true significance of Pütter's theory — as possibly applicable to some Protozoa and Sponges and perhaps, pending further knowledge on these matters, to members of the fauna of caves and the abyssal seas. Marine biologists may now, with a sigh of relief and with gratitude to their deliverer, turn their attention to less barren controversies and more fruitful lines of research. C. M. Yonge.

A. Willer. Vergleichende Untersuchungen an Strandgewässern. (Arbeiten No. 72 aus dem Fischerei-Institut der Universität Königsberg Pr.) Verhandlungen der internationalen Vereinigung für theoretische und angewandte Limnologie. Bd. V, S. 197—231. (no date).

In this paper the author embodies the results of researches upon the hydrographical and biological conditions obtaining in partially or completely landlocked coastal lagoons or lakes (Strandgewässern) which have permanent or intermittent communication with the sea. After describing a number of such lagoons and discussing their general characters and probable origins, he proceeds to give a detailed account of recent researches in two of them — the Kurisches Haff and the Frisches Haff on the east Prussian coast.

In so far as they both possess extremely complicated systems of currents, cross currents, and eddies, and show complex haline and thermal stratifications which vary greatly under the influence of weather conditions these two lagoons are very similar to each other. But they differ widely in other respects.

Though situated quite close to each other and both possessing direct communication with the sea, the waters which fill the basin of the Kurisches Haff are practically fresh while those of the Frisches Haff are predominantly brackish in character. Several causes are found to combine to produce this result, the most important of which is that in the Frisches Haff, owing to the nature and position of the connecting channel, the incoming sea-water can in certain circumstances completely dam back the waters of the river Pregel which flows into it. The river is then forced to empty itself — by the flooding of connecting streams — into the neighbouring Kurisches Haff. Such heavy inrushes of sea-water, with consequent damming back of the fresh, does not occur in the latter lagoon.

In ordinary circumstances, the oxygen content of the waters in both lagoons is fairly uniform from surface to bottom. But there may be great variation in the horizontal distribution of oxygen concentration. A specially interesting point is brought out in the fact that in those zones where salt and fresh waters abruptly meet — as for example, along the edges of a salt-water current which may retain its identity while penetrating for a long distance through the lake waters — the oxygen concentration is surprisingly low. This the author attributes to the fact that, at such places, there is a relatively very high mortality of both marine and freshwater planktonic organisms and therefore maximum decomposition of organic matter, with consequent diminution of oxygen content. Unusually high oxygen concentrations are generally found where there is a good growth of aquatic plants.

The plankton production of the Kurisches Haff is on an average from three to five times as rich as that of the Frisches Haff. Moreover the composition of the plankton is very different in the two lagoons. In the former, the phytoplankton predominates, while in the latter there is a greater production of zooplanktonic than of phytoplanktonic organisms as volumetrically determined from plankton samples. Even so, the absolute production of zooplankton is higher in the Kurisches than in the Frisches Haff.

On the other hand, the Kurisches Haff is much less productive of bottom-living organisms than is the Frisches Haff, as regards the number of individuals over most of its area although it appears to possess quite as many species. This is due, in part at least, to the nature of the bottom deposits in the two lagoons, there being relatively much more sand and less mud in the former than in the latter; and muddy bottoms are found to have the richest fauna.

Finally the fisheries of the two lagoons are briefly compared as regards both the species taken and their contributions to the catches. Of sea fishes, only the Herring (*Clupea harengus*, var. *membras*) and the Flounder (*Pleuronectes flesus*) are of economic importance. By far the heaviest landings of both these fishes are recorded from the Frisches Haff. The average values of the yields from the two lagoons for the ten-year period 1892—1901[1]) are stated to be: Flounder — 130 and 0.19 marks per square kilometre; Herring — 90 and 8.44 marks per square kilometre, from the Frisches and Kurisches Haff respectively.

The freshwater fishes of economic importance the author divides into bottom-feeders and plankton-feeders. Of bottom-feeding species the Ruffe (*Acerina cernua*), the Bream (*Abramis brama*), and the Eel (*Anguilla vulgaris*) are present in both lagoons. Interesting data regarding the average sizes reached by the Bream in the two places are given. Those inhabiting the Frisches Haff grow commonly to a length of 18 cm. while those in the Kurisches Haff seldom exceed 12 cm. in length. The average value of the yield of fish per square kilometre for the ten-year period 1892—1901 is also very much less in the Kurisches Haff: those of the Ruffe and Bream being roughly one third, and that of the Eel roughly one half of the corresponding yield from the Frisches Haff. This very marked difference in the

[1]) The more recent statistics are not comparable.

yield of fish from the two lagoons — as is also the difference in size of the Ruffe — is attributed by the author to the difference in the amount of food available in the two places.

Of plankton-feeding fishes in the two lagoons, the Smelt (*Osmerus eperlanus*) and the Pike-perch (*Leucoperca sandra*) are the most important commercially. Here again, at any rate in the case of the Smelt, the largest catches are taken in the lagoon with the most abundant food supply — this time the Kurisches Haff. The landings of Pike-perch, however, are smaller in the Kurisches Haff — a fact which the author thinks must be explained by differences in the fishery; for he believes, on the strength of the other data in his possession, that this lagoon does actually support the larger stock of these fish. This point, however, requires further work for its elucidation. G. A. S.

G. H. Nall. The Life of the Sea Trout. Seeley, Service & Co. London, 1930.

The Fishery Board for Scotland has for many years carried out investigations of great value on the life history of the salmon and sea trout. The development of the technique of scale reading provided a method which has been utilised with great skill and energy, in conjunction with the marking of fish. The sea trout investigations, commenced by Mr. W. J. M. Menzies, have been carried out mainly by Mr. Nall. He has studied the age and growth of sea trout in some twenty rivers in Scotland, two in England and five in Ireland. The results obtained from these detailed studies are here presented in a form suitable both for the general reader and for the student. In addition, there are chapters on classification, origin and distribution, and on the sea trout in other countries than Scotland. As regards the origin of sea trout, Mr. Nall adopts whole-heartedly the views of Dr. Tate Regan. These are, in short, that the existing species of Salmonidae are descended from marine forms which acquired the habit of spawning in fresh water, where some of them ultimately formed permanent colonies. According to these views, then, the salmon and sea trout have retained the ancestral habit of resorting to the sea, which the brown trout and many other species have lost. All the recent species of salmonidae spawn in fresh water and it is incredible that this habit should have been acquired by each species. It is a legitimate inference, therefore, that the common ancestor also spawned in fresh water. For this and for many other reasons it is difficult for some of us to accept the marine origin of the salmonidae.

The specific identity of the migratory and non-migratory forms of trout has now been generally accepted and Dr. Knut Dahl has maintained that, under appropriate conditions, the one form may be readily transformed into the other. Mr. Nall, whilst accepting the specific identity of the two forms, is inclined to attach considerable importance to the differences in habit, the assumption of the silvery coat by sea trout smolts and to certain differences which he finds in the ridges on the scales of the two forms.

Mr. Nall has finally disposed of the "bull trout" as a distinct species by showing that no Scottish river has more than the one race of migratory trout and that in certain rivers where the name is used, such as the Tweed, it has been applied to the larger individuals of the species.

Mr. NALL does, however, distinguish two main groups, more or less distinct, of sea trout in Scottish waters, which he calls the east coast and west coast types. The former extends up the east coast as far as the Moray Firth or the Kyle of Sutherland, the latter occupies the north-east, north and west coasts. A third type occupies the Hebrides. These types he correlates with differences in the character of the rivers which they occupy. The east coast rivers are long, mainly lowland in character, as a rule are without fresh-water lochs near the sea but have long tidal estuaries. The rivers of the north and west coasts are short, usually have large fresh-water lochs near the sea and their estuaries are short. The Hebridean sea trout waters consist of chains of small lakes joined by short rivers. The influence exerted on the sea trout by these three types of environment affects their habit and growth and is reflected in the structure of their scales. The east coast type shows the more rapid growth, tends to spawn at an earlier age and on fewer occasions and has a shorter life than the west coast type. Mr. NALL finds these two types of trout in other countries, associated with corresponding conditions in the rivers which they occupy.

It was formerly considered that sea trout differed from salmon in their tendency to remain in the sea near the river where they were born, whilst salmon made long migrations. The Scottish marking experiments have shown that this opinion must be modified, since marked sea trout have frequently been taken at considerable distances from their native rivers.

The chapter on the food of the sea trout reflects the inadequacy of our knowledge of the subject and it is satisfactory to know that, largely through the instrumentality of Mr. NALL, investigations on this very important matter are now in progress.

A knowledge of the age, growth and migrations are of fundamental importance for a proper understanding of the sea trout, and this foundation is well and truly laid by Mr. NALL in this book. There are, however, many other aspects of the life-history of the salmon and trout of which our knowledge is very meagre. We know very little of the various factors which control their growth and reproduction, of their relation to the environment, of their food and its abundance in various types of water, of the maximum stock which a river can carry or of the number of fry which a stream can support. We may expect that, in the near future, investigations concerning themselves with salmon and trout will deal with these matters. R. S.

L. Lambert. Les gisements huîtriers de la baie du Mont Saint-Michel. Revue des Travaux de l'Office des Pêches Maritimes. Tome IV, Fasc. 3, No. 15. Paris, 1931.

In this article the author traces the decline of the oyster fisheries in the region of Cancale and Granville from periods of remarkable productivity and reckless exploitation in the eighteenth century, through others of scarcity and of partial recovery up to the disastrous mortality some ten years ago and their present condition of exhaustion. He then describes measures which have just been taken to bring about resuscitation of the beds in the bay.

In the introductory topographical note there is mention of the evidence of pre-historical submergence of the former coast, which brought about

the present configuration of the bay and cut off Jersey and other points from the mainland. More than once during the early history of the beds they were given a much needed opportunity for recovery during the lull in dredging which followed each outbreak of war. The extent of exploitation can be realised from the table giving the number of boats from both Normandy and English coasts engaged in removing oysters from the bay of Cancale each year from 1767 to 1785, when certain restrictions including a close season were in force. Thus in 1775 there were no fewer than 330 boats working, of which over 100 were English and took oysters largely to stock beds near Southampton, an enterprise which failed completely. The cargoes removed from the bay that year are estimated to have comprised over ninety million oysters in addition to those landed locally. The number of boats fell to 26 a few years after, but the average for the nineteen years mentioned was little less than forty million oysters annually. During the first decade of the nineteenth century barely a million oysters a year were taken, but another period of prosperity returned about 1840, followed again by comparative scarcity which has continued ever since. Details and maps are included giving the condition of each administrative division of the bay before the mortality. The description of the measures taken to revive the beds with financial aid from the government illustrates the difficulties of securing agreement among those for whose benefit such tasks are undertaken. In this case they were accentuated by rivalry between the ports chiefly concerned. After trial layings, about four million oysters obtained from Morbihan were put down during the spring of 1931 on the bed selected for the purpose, which was then strewn with concrete blocks bearing iron hooks to discourage illicit dredging. The whole story is presented very readably, and has special interest for those concerned with the conservation of oyster fisheries or with communities dependent on inshore fisheries. H. P. S.

P. Voisin. Recherches sur la reproduction des huîtres indigènes dans le Morbihan. Revue des Travaux de l'Office des Pêches Maritimes. Tome IV, Fasc. 4, No. 16. Paris, 1931.

Among the centres of production of the flat oyster in France the long inlets or "rivers" of Auray and of la Trinité (the Crac'h river) are specially favourable. Investigation of the factors responsible is therefore desirable. While the upper Auray beds are fairly well populated, serious depletion is, however, evident on the lower beds and in the Crac'h at present. This paper contains the authors observations during 1931 in the inlets mentioned. Progress of spawning was noted by examination of oysters and of surface townet catches, the numbers of larvae present being estimated, and also the ratio between those in the "first stage" (with straight hinge lines) and those in the "second stage" (in which the umbo is prominent). In spite of an unusually wet and cold spring and summer, spawning appeared to be distinctly above the average on the lower Auray beds, where larvae were taken in numbers which had not been approached among the few observations previously made in the locality. One five-minute haul on July 8th, for example, took 850,000. Spawning on the other beds was only slightly more profuse than during the previous year. In the Crac'h it was evenly distri-

buted. The ratio of first to second stage larvae was fairly constant over a period of three weeks during which the main spawning occurred. It was impossible therefore to trace the growth of successive broods of larvae. Satisfactory setting followed, and the tiles were well covered with spat.

As the author points out, the observations which he has recorded serve to emphasise our ignorance of the factors which control the spawning of the oyster and their relative importance, and also the difficulty of making predictions even a week or two ahead. In fact they accomplish little more than defining the extent of spawning as it occurs. Incidentally there is much to be said for straining measured volumes of water taken by means of a pump and hose when possible, in preference to ordinary use of the townet for serious quantitative studies of the horizontal and vertical distribution of oyster larvae, without which their movements and the influence of local conditions can hardly be understood.

An examination is in progress of the plankton present during the summer in these inlets. Comparison of the volumes of the catches taken along with the oyster larvae has given a rough indication of the extent of variations in quantity from day to day. The whole investigation is clearly at an early stage, observations extending over a considerable period of years being essential before the characteristics of the locality can be understood or generalisations attempted. H. P. S.

Erratum.

With reference to the "Guide to Fish Marks" published in the last number of the Journal, the following correction should be made:

p. 134. Instead of "FD ..... Germany" read "FD .... Danzig".
p. 148. Instead of "Germany (Danzig)" read "Danzig".

Current Bibliography.

Prepared by the Editor with the assistance of Miss THURSBY-PELHAM.

NOTE. The scope of the Bibliography is limited in the main to the area covered by the Council's activities, but there are included papers of general interest relating to other areas in the North Temperate and Arctic regions and exceptionally elsewhere. Limnological references are not as a rule given, but papers relating to brackish waters and to salmon and freshwater fish studied by the Council are included.

The classification of entries follows in a general way that adopted in Dr. ALLEN's Selected Bibliography published in Vol. I, Nos. 1 and 2 of the Journal, and since reprinted (Price, 1 Kr.).

Subscribers and those on the distribution list will receive regularly upon application to the Administrative Secretary copies of the Bibliography printed on one side of the page only, for use in making up card indices.

The Editor will be glad to be advised of emendations and additions to the Bibliography.

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